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The University of Montana

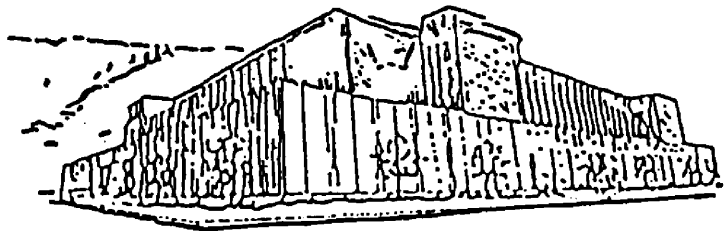
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**ABUNDANCE AND NESTING SUCCESS OF
CAVITY-NESTING BIRDS IN UNLOGGED AND SALVAGE-LOGGED
BURNED FOREST IN NORTHWESTERN MONTANA**

by

Susan M. Hitchcox

B.S., Cornell University, 1988

Presented in partial fulfillment of the requirements

for the degree of Master of Science

UNIVERSITY OF MONTANA

1996

Approved by:



Chairperson



Dean, Graduate School

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Abundance and nesting success of cavity-nesting birds in unlogged and salvage-logged burned forest in northwestern Montana

Advisor: Richard L. Hutto *RLH*

I studied cavity-nesting bird communities in a northwestern Montana coniferous forest following a severe, stand-replacement fire. I surveyed for active cavity nests for three years following the fire. Half of the area surveyed had been salvage-logged in the winter following the fire, while the other half was left unlogged. I compared nest density, cavity re-use over time, nest tree characteristics and nesting success in the two treatments.

Unlogged areas had more cavity-nesting bird species nesting at significantly higher densities compared to salvage-logged areas. Timber-drilling foragers like Black-backed Woodpecker (*Picoides arcticus*), Three-toed Woodpecker (*Picoides tridactylus*), Red-naped Sapsucker (*Sphyrapicus nuchalis*) and Williamson's Sapsucker (*Sphyrapicus thyroideus*) nested in unlogged areas in low numbers but were absent from salvage-logged areas. Several ground-brush foraging species [House Wren (*Troglodytes aedon*), Mountain Bluebird (*Sialia currocoides*), Northern Flicker (*Colaptes auratus*)] nested in both salvage-logged and unlogged areas, but nested in higher densities in unlogged areas.

Diversity and density of primary-cavity-nesting bird species was lower in salvage-logged compared to unlogged areas. Northern Flicker was the main excavating species nesting in salvage-logged areas. Cavity re-use rates were higher in salvage-logged (47%) than unlogged areas (31%).

I assessed characteristics of nest trees and their associated microsites (area within 15-m radius of nest) for 12 species of cavity-nesting birds. I examined the same characteristics at random trees, and compared these to characteristics at nest trees to estimate suitability of each random tree and associated microsite for each bird species. In general, cavity-nesting birds used trees that were larger in diameter than random trees in salvage-logged areas, and shorter than random trees in unlogged areas. Nests were in broad-leaved deciduous trees, western larch, and broken snags more often than expected based on the availability of these trees in either treatment. The availability of suitable nesting trees appeared to explain patterns of nest abundance for some species but not for others.

Nesting success was assessed during the 1995 breeding season for Northern Flicker, Mountain Bluebird and House Wren. Daily survival rates for Northern Flicker were significantly higher in unlogged compared to salvage-logged areas. Nesting success varied from 34% for Mountain Bluebirds in salvage-logged areas to 95% for Northern Flickers in unlogged areas. Only microsite tree density in one size class (10-20 cm dbh) for one species (Mountain Bluebird) was significantly different between successful and failed nests. No other tree or microsite characteristics measured for any other species was correlated with nesting success.

Acknowledgements

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My mother has always supported my every endeavor and for this I am grateful. Her belief in my abilities has helped me to believe in myself. My husband Geoff Poole, has been an unwavering source of support and encouragement since the very beginning, but deserves a special thanks for his patience, kindness, and generosity during these last few years.

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CHAPTER I

ABUNDANCE OF BREEDING CAVITY-NESTING BIRDS IN SALVAGE-LOGGED VS. UNLOGGED BURNED FOREST PATCHES

Introduction

Primary cavity-nesting birds in the northwestern United States depend on standing dead trees, or snags, for both foraging and cavity excavation (Thomas et al. 1979, Bull et al. 1986). Secondary cavity-nesting birds rely mainly on the creation of cavities by primary cavity-nesting birds for nesting, so in turn are also dependent on snags (Balda et al. 1983). Snag density in unburned forest often correlates with cavity-nesting bird abundance, both in natural and managed forest stands (Dickson et al. 1983, Marcot 1983, Scott and Oldemeyer 1983, Zarnowitz and Manuwal 1985, Schreiber and deCalesta 1992). Numerous recommendations for snag retention during timber harvests have been made to mitigate the loss of cavity-nesting birds and other wildlife species in unburned, managed forests (Jackman 1974, Thomas et al. 1979, Morrison and Raphael 1983, Raphael 1983, Raphael and White 1984, Zarnowitz and Manuwal 1985, Bull and Holthausen 1993). Many of these recommendations are incorporated into current management plans for unburned forests.

Intense, stand-replacement fire was an ecologically important disturbance agent in forests of the northwestern Rocky Mountains prior to European settlement (Gruell 1983). Stand-replacement fires created a mosaic of green, unburned areas interspersed with

stands of dead trees, or snags (Turner and Romme 1994). The ecological importance of this type of forest habitat is reflected in the fact that the avian community found in forests after stand replacement fires is unique, and contains several species (e.g., Black-backed Woodpecker, Mountain Bluebird) that appear to be relatively restricted to burned areas (Hutto 1995a, 1995b). The abundant standing snags in post-fire forests are a key component of post-fire habitat used by cavity-nesting birds for both foraging and nesting (Caton 1996).

Salvage-logging is the practice of removing economically valuable dead and dying timber from a forest, and is common in the western United States after high-intensity, stand-replacement fires. The National Forest Management Act and the National Environmental Protection Act both relax environmental standards for salvage-logging after fire, and exempt salvage-logging sales from most forest plan standards (Beschta et al. 1995). Snag retention policies that are in place for harvests in unburned forests are generally not applied to salvage-logging operations. Much of the public's attitude toward, and acceptance of, the relaxed environmental standards for salvage-logging practices stems from the perception that forest fires are "negative and destructive" (Habeck and Mutch 1973) and leave behind fire-damaged timber that, other than as salvaged lumber, "does no one any good" (Powell County Commissioners, 1992).

There are very few data published on the impacts of salvage-logging on cavity-nesting birds. Raphael and White (1982) found a 77% reduction in cavity-nesting bird density following post-fire snag removal on one plot in the Sierra Nevada Mountains of California. Blake (1982) found the fewest numbers of cavity-nesting bird species during

the non-breeding season on a plot in Arizona that had been clearcut salvage-logged following a fire, compared to a partially salvage-logged and an unlogged burned forest plot. Lyon and Marzluff (1984) surveyed birds in two burned forest plots in northwestern Montana before and after salvage-logging, and found fewer species and lower densities of birds after salvage-logging. This was true even though the pre-salvage-logging census period was shorter and started later in the season than the post-salvage-logging census period. Harris (1982) conducted transect surveys for non-breeding birds in logged and unlogged portions of two burned areas in northwestern Montana. She found more species of cavity-nesting birds and slightly higher densities on unlogged compared to salvage-logged transects. Finally, Caton (1996) surveyed breeding cavity-nesting birds for four seasons in unlogged burned forest in Glacier National Park and in neighboring Flathead National Forest land that had been either completely or partially salvage-logged. She found higher breeding cavity-nesting bird densities and higher species richness in unlogged burned forest.

The general paucity of information on the impacts of salvage-logging on cavity-nesting birds during the breeding season over multiple years on replicate plots lead to the formulation of the present study. The objectives of this study were 1) to assess breeding cavity-nesting bird abundance in salvage-logged vs. unlogged burned forest patches and 2) to document the re-use of cavities over time, especially the re-use of cavities created by primary cavity-nesting birds.

Methods

Study Area

This study took place on the Blackfoot-Clearwater Wildlife Management Area, which is located about 80 km east of Missoula, MT. Elevation of the study area is between 1200 and 1500 m. A severe fire in October of 1991 burned approximately 1600 ha of grassland and mixed-conifer forest. Approximately 500 ha of timber was salvage-logged in the winter following the fire (1991-1992) in a design that created an interspersed pattern of harvest treatments with unlogged control plots (Figure 1). Both unlogged and salvage-logged forest plots were separated mainly by grasslands. The forested burned areas consisted mainly of 50 to 150-year-old second-growth conifers [Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), and ponderosa pine (*Pinus ponderosa*)] with occasional pockets of broad-leaved deciduous trees (*Populus* spp.).

Eight unlogged plots (totaling approximately 148 ha) and seven salvage-logged plots (totaling approximately 134 ha) ranging in size from 7 to 34 ha each were selected for this study (Figure 1). Plots were delineated in part based on timber harvest prescriptions provided by logging companies. The extent of salvage-logging varied among plots, but in most cases all merchantable (>15 cm dbh, >4.5 m tall), fire-killed timber was removed.

In order to characterize the physiognomy of the two treatments, I measured vegetation characteristics at 132 random trees in unlogged plots and at 112 random trees in salvage-logged plots. Random trees were selected by locating random grid points on high resolution aerial photos (scale: 1 inch = 100 feet). If a grid point fell on a tree, that

tree was selected as a random tree. Otherwise the point was discarded. Grid points were repeated until all random trees had been identified. Random trees were located on the ground with the aid of the aerial photos.

Vegetation characteristics measured at random trees included tree size (diameter at breast height, measured with a dbh tape), tree height (measured with a clinometer), tree species, tree status (live or dead; intact, bent, or with a broken or dead top) and percent of bark (estimated visually). To assess vegetation characteristics of the microsite around random points, stakes were placed 15 m from the tree in the four cardinal directions. Ocular estimates of the percent of bare ground (bare soil), ground cover (herbaceous plants <25 cm tall), low shrub (herbaceous plants >25 cm tall plus woody plants <0.5 m), and tall shrub (woody plants > 0.5 m tall) were made in each quarter and then averaged for the microsite. These estimates were made from a “birds-eye” perspective (i.e., only the top layer was estimated so the four estimates summed to 100%). Burn severity of the canopy in the microsite was rated on a subjective scale of one to six, 1) 100% green, 2) 40-60% green, 3) <40% green, 4) no green but brown needles, 5) no brown needles but some twigs, and 6) no twigs but some branches.

Nest Searches

Active cavity nests were located by searching these 15 forest plots during the breeding season from mid-May through mid-July of 1993, 1994, and 1995. I walked parallel transects through the plots. Transects were approximately 20 m apart. When there were two observers searching for nests (during the entire 1996 breeding season and occasionally during other years), side-by-side transects were walked at approximately the

same speed. My objective was to systematically search entire plots for active nests. Plots were designed to be large enough that they required between one and two days search time to cover the entire plot. I searched plots at least twice during each breeding season, and walked transects in the opposite direction each time to maximize chances of finding all cavity-nesting bird nests. Nests were located by finding cavities and observing subsequent activity, following adult birds to nests, or hearing young birds at the nest. I recorded activity of birds at the nest (building, incubating or feeding) at the time the nest was found, and the type of cavity used (excavated or natural).

The first time a nest was found active, it was considered to be a new nest. In subsequent years, these nests were checked for activity. Cavities active in subsequent years were then considered to be re-used nests. Cavities active with a second pair of breeding birds in one breeding season were classified as repeat nests .

Data Analysis

Vegetation characteristics of random trees and microsites in the two treatments were compared using Mann-Whitney U tests for numerical data, and Chi-Square Likelihood ratios for categorical data. A Bonferonni correction for experiment-wise error was applied to adjust the p-value for 13 simultaneous tests (for $\alpha > 0.95$, $p < 0.0038$).

Nest abundance was converted to nest density by averaging the number of nests per plot for each treatment and for each year of the study. Differences in nest density for all species combined over the three years of study were tested with repeated measures ANOVA. Density data was transformed by the inverse of the square root in order to

achieve normality. Differences in density for each species between the two treatments was tested with Mann-Whitney U tests. Independence of nest abundance by species and treatment type was tested with a Chi Square Likelihood ratio. A Chi Square Likelihood ratio was also used to test for independence between foraging guilds and treatment types. T-tests were used to test for differences in primary and secondary cavity-nesting bird density between the two treatments.

The number of re-used cavities was compared between salvage-logged and unlogged treatments. Further analysis of cavity re-use was limited to cavities known from direct observation to be excavated by primary cavity-nesting birds. The number and types of species re-using these cavities was explored.

Results

Vegetation Characteristics

Unlogged plots had significantly higher densities of larger and taller trees compared to salvage-logged plots (Table 1). Trees in unlogged areas had more bark than trees in salvage-logged areas (Table 1). Unlogged plots had more live trees compared to salvage-logged plots, and correlating with this, unlogged plots were less severely burned compared to salvage-logged plots (Table 1). There was a higher proportion of intact snags in salvage-logged plots (Table 1).

Nest Abundance

Most cavity nests were found in June, with a peak period of nest-finding between 8 and 23 June in both salvage-logged and unlogged areas (Figure 2). Most nests were

identified by following adult birds to the cavity (Table 2) and most were active with young when they were found (Table 2). Eighty-three percent of nests in unlogged plots and 77% of nests in salvage-logged plots were in cavities originally excavated by primary cavity-nesting birds.

I found a total of 563 active nests (Table 3) of 18 cavity-nesting bird species (Table 4). All 18 bird species nested in unlogged areas, whereas only 8 species nested in salvage-logged areas (Table 5). The total number of active nests found in unlogged plots was almost three times higher than the total number of nests in salvage-logged plots (Table 5). Mean density of all species combined was also significantly higher in unlogged compared to salvage-logged areas for each year of the study (Figure 3). Density increased significantly over the three years of study. Relative abundance of species differed significantly between the two treatments (Figure 4). The most abundant species in unlogged areas were also the most abundant in salvage-logged areas (e.g., Northern Flicker, House Wren, Mountain Bluebird), but all nested in higher densities in unlogged compared to salvage-logged areas (Table 5). Rare species like Black-backed and Three-toed woodpeckers, and Red-naped and Williamson's sapsuckers, nested in low densities in unlogged areas and were absent from salvage-logged areas (Table 5).

Foraging Guilds

Distribution of nests among foraging guilds was significantly different between salvage-logged and unlogged areas (Figure 4). Most species in both treatments were ground-shrub foragers, and 74.6% of nests belonged to species in that guild (Figure 4). Hairy Woodpeckers were the only timber drillers to nest in salvage-logged plots. Tree

Swallows were the only aerial insectivore, and Black-capped Chickadees were the only timber foliage searcher to nest in salvage-logged plots (Figure 4). Timber gleaners were absent from salvage-logged plots (Figure 4).

Primary vs. Secondary Cavity-Nesting Birds

Primary and secondary cavity-nesting species were defined based in part on Ehrlich et al. (1988) and in part on personal observations of nesting behavior during the course of study (Table 4). Northern Flickers and Hairy Woodpeckers were the only species of primary cavity-nesting birds to nest in salvage-logged plots; they also nested in unlogged plots, along with six other primary cavity-nesting species (Figure 4). Mean density of primary cavity-nesting birds over the three years of study was significantly greater in unlogged compared to salvage-logged plots (Table 6). Primary cavity-nesting birds comprised about a third of the total cavity-nesting bird community in either treatment (Table 6).

Secondary cavity-nesting birds were more numerous than primary cavity-nesting birds in both treatment types (Table 6). Mean density over the three years was significantly higher in unlogged compared to salvage-logged plots. Six species of secondary cavity-nesting birds nested in both salvage-logged and unlogged plots. An additional four species nested exclusively in unlogged plots (Figure 4).

Cavity Reuse

Thirty-four percent of the cavities found in 1993 were re-used by cavity-nesting birds the following year (Table 3). In 1995, 35.7% of cavities used for nesting during

either or both of the two previous years were re-used. Cavity re-use rates in salvage-logged areas ranged from 50% in 1994 to 44% in 1995. In contrast, re-use rates in unlogged areas were substantially lower: 30% in 1994 and 33% in 1995 (Table 3). A small number of cavities (2.4%) in 1995 were used twice in one breeding season. Mountain Bluebirds, House Wrens, and Northern Flickers were the three species that most often used re-used cavities for nesting. Interestingly, 27.3% of Northern Flicker nests were in previously-used cavities.

There were 128 cavities known by observation to be excavated by primary cavity-nesting birds. Of these, 58 were re-used at least once during subsequent years (Table 7). Half were re-used by Northern Flickers (Table 7). Most of these were Northern Flickers re-nesting in their own holes, although they also expanded holes already excavated by other species (Table 7). A small number of Red-naped and Williamson's sapsuckers re-used holes excavated by Red-naped Sapsuckers (Table 7). Mountain Bluebirds and House Wrens together used over a quarter of the cavities originally made by primary cavity-nesting birds (Table 7).

Discussion

The physiognomy of the two treatments was significantly different due to the selective removal of large-diameter, tall trees during salvage-logging. Unlogged plots had more live trees compared to salvage-logged plots, so they were likely less severely burned than areas that were salvage-logged. The decision of where to salvage-log in the first place may have been in part decided based on the severity of the fire, and may have contributed to differences in bird community composition found after salvage-logging.

Shrub and herbaceous cover were similar between treatments. Salvage-logging may have had minimal effects on vegetation growth, since the removal of dead trees likely did not significantly change growth conditions on the forest floor. Similar vegetation cover could indicate similar foraging opportunities for bird species that feed on insects on shrubs and on the ground. However, I did not record species composition for any of the cover classes. Differences in plant species could lead to differences in insect populations. Anecdotally, there appeared to be more noxious weeds (e.g., *Centaurea maculosa*) in salvage-logged areas, and the presence of these non-native species may have contributed to differences in insect populations, and in turn, to differences in cavity-nesting bird populations.

The peak period of nest finding during all three years of study was between 8 and 23 June. This appeared to be when cavity-nesting birds had settled into their nesting cavities for incubation or had started to feed young. Searching for nests before this peak time was often fruitless, as many birds, especially secondary cavity-nesting species, appeared to be examining cavities without settling on their use. Toward the end of June, nestlings started to fledge and the number of active cavities began to drop. During the peak period of nest finding, following adults who were feeding young was the most efficient method of locating nests. Auditory cues from loud nestlings at cavities, especially from young woodpeckers, aided in nest location during this stage of nesting.

The range of nest densities found in this study (14.57 nests/40 ha in salvage-logged plots to 38.58 pairs/40 ha in unlogged burn) is at the low end of ranges reported for cavity-nesting bird communities in other studies in unburned habitat types (e.g., Scott

and Oldemeyer 1983, Zarnowitz and Manuwal 1985, Sedgwick and Knopf 1992).

However, the density of cavity-nesting birds in unlogged burned forest plots was similar to what has been reported for other burned areas. Bock and Lynch (1970) found 12 species of cavity-nesting birds nesting at a density of 38.9 pairs/40 ha in unlogged burned forest in the Sierra Nevada of California. Taylor and Barmore (1980) reported average cavity-nesting bird densities of 38.0 pairs/40 ha during the first three years following fire in unlogged lodgepole pine stands in Yellowstone National Park. Caton (1996) reported cavity-nesting bird nest densities of 4.92 nests/40 ha in burned, unlogged forest stands in Glacier National Park, and densities of only 2.52 nests/40 ha in salvage-logged portions of Flathead National Forest. Both of these densities are much lower than what was found in the current study. This could be explained in part by differences in forest type, and in part by a difference in sampling method. Caton (1996) used line transect distance sampling to estimate nest densities, whereas I used closely-spaced parallel transects to repeatedly search entire plots for nests.

Searching entire plots for nests as a method of locating nests has several potential biases. I spent approximately the same number of hours per hectare searching for nests in each treatment type. However, since salvage-logged plots had fewer trees and increased visibility compared to unlogged plots, I probably over-sampled salvage-logged plots relative to unlogged plots. This bias is conservative, in that, if anything, I underestimated nest density in unlogged areas and overestimated nest density in salvage-logged areas. Unusual or unique nests may have had a greater chance of being discovered with this

method of nest searching. Also, nests of loud species were likely more easily detected, although this is a bias with most nest searching protocols.

Higher abundance and species richness of cavity-nesting birds in unlogged compared to salvage-logged burned areas in this study are consistent with previous findings by Harris (1982), Lyon and Marzluff (1984) and Caton (1996), who found fewer cavity-nesting bird species and lower densities in salvage-logged vs. unlogged burned forest in northwestern Montana. Studies in other burned areas (e.g., Arizona (Blake 1982) and California (Raphael and White 1984)) also revealed lower species richness and lower cavity-nesting bird density in salvage-logged compared to unlogged areas.

Rare species like Black-backed and Three-toed woodpeckers nested in low numbers in unlogged burned forest, and were absent from salvage-logged areas (Figure 4). Both of these species, but especially Black-backed Woodpeckers, appear to be relatively restricted to burned areas in the northern Rocky Mountains (Hutto 1995a, Hutto 1995b). The number of nests of both these species decreased over the three years of study, which is also what Caton (1996) found in early post-fire habitat in Glacier National Park.

Density of cavity-nesting birds increased over time (Figure 3). More effort was spent in later years of the study searching for cavities, and cavities found in previous years were easily relocated and checked each subsequent year. This likely explains some of the increase in abundance. However, since I am fairly certain that I met my objective of thoroughly searching every plot for nests, it is likely that the density of cavity-nesting birds is in fact increasing over time, due in part to the creation of cavities by primary

cavity-nesting birds and their use in subsequent years by both primary and secondary cavity-nesting birds.

Birds in the ground-shrub foraging guild were more common than birds in other guilds in both salvage-logged and unlogged burned forest. This finding is similar to that of several other studies. Apfelbaum and Haney (1981) in Minnesota found the number of species of ground-brush foragers increased after a fire, though their density did not change. Bock and Lynch (1970) reported that ground-brush foragers (including Northern Flicker, House Wren, and Mountain Bluebird) were the most dominant foraging group found on a post-fire forest plot in the Sierra-Nevada. Sallabanks (1995) reported increased numbers of Mountain Bluebirds and Northern Flickers with increasing burn severities in Idaho. The abundant ground cover that grows after fire likely provides an ideal foraging substrate for this guild, and snags are used by these species for both perching and nesting. Where standing snags were lacking in the salvage-logged areas, birds in this guild were often seen perching on the branches of downed snags.

The abundance of nests of timber drillers was reduced in salvage-logged areas. This may be due to the reduction in number of snags, their main foraging substrate, in salvage-logged areas. Interestingly, many of the small, unmerchantable snags left standing in the salvage-logged areas showed evidence of foraging by woodpeckers, even though woodpeckers were rarely seen in salvage-logged areas during the breeding season. Despite the apparent abundance of foraging substrate in unlogged areas, timber drillers were using salvage-logged areas for foraging, possibly in the non-breeding season.

Tree Swallows were the only aerial insectivore to nest in salvage-logged areas.

Tree Swallows may find abundant food above the lush undergrowth of the burn in both unlogged and salvage-logged areas. Their small size may allow them to nest in cavities in smaller snags, and this may give them increased opportunities for nesting in salvage-logged areas as well. The other species of cavity-nesting aerial insectivore on this study area was Lewis Woodpecker, which nested only in the unlogged areas in low numbers. Harris (1982) recorded Lewis' Woodpeckers only in salvage-logged burned forest, but Saab (pers. comm.) found them in large numbers in burned, unlogged ponderosa pine forests in Idaho.

Timber foliage searchers nested in low densities in both unlogged and salvage-logged burn. Bock and Lynch (1970) did not find any timber foliage searchers on a burned plot in California. Foliage searchers decreased as degree of burn increased from unburned to highly burned forest in Idaho (Sallabanks 1995). Timber gleaners were absent from the salvage-logged areas in this study. The density of timber gleaners decreased after a fire in Minnesota pine/spruce forest (Apfelbaum and Haney 1981). Timber gleaners and timber foliage searchers were probably at low densities or absent from salvage-logged areas since they generally require live foliage for foraging, and most trees left standing in the salvage-logged areas were dead. The few live trees that were left in unlogged areas may have been enough to support low densities of timber gleaners and timber-foliage searchers.

Northern Flickers and Hairy Woodpeckers were the only primary-cavity-nesting species to nest in salvage-logged areas. Northern Flickers nest in clearcuts in unburned

forest, even when there are few snags left behind (Conner et al. 1975, Marcot 1983, Scott and Oldemeyer 1983, Zarnowitz and Manuwal 1985). On the salvage-logged plots of this study, Northern Flickers often nested in rotten trees, and several nests were in old, cut stumps. One Northern Flicker nest was in a stump less than a meter tall! Northern Flickers may find adequate nesting substrate in salvage-logged areas since logging leaves behind a variety of stumps as well as old snags that were dead before the fire.

Hairy Woodpeckers also nest in unburned clearcuts, but their presence there appears to be more closely related to the abundance of snags retained during harvest (Dickson et al. 1983, Zarnowitz and Manuwal 1985, Scott and Oldemeyer 1983). Enough remnant snags may have been retained through this salvage-logging treatment to allow for the small number of Hairy Woodpeckers that nested in salvage-logged plots. Hairy Woodpeckers also nested in both partially cut and clearcut salvage-logged burned forest in Glacier National Park (Caton 1996). Caton (1996) also found several other species of woodpecker (e.g., Three-toed Woodpecker, Black-backed Woodpecker, Downy Woodpecker, Red-naped Sapsucker) that nested in partially salvage-logged burned stands. Variations in the types and intensities of salvage-logging may allow birds to nest in salvage-logged areas if their other life-history needs are met. The high-intensity salvage-logging on this study area eliminated all but two primary-cavity nesting bird species.

Unlogged plots had more than twice as many secondary cavity-nesting bird nests as salvage-logged plots, but the density of secondary cavity-nesting birds in unlogged plots was still lower than that reported by other researchers in other unburned habitat

types (e.g., Brawn and Balda 1988, Sedgwick and Knopf 1992). Other researchers have also found that cavity-nesting bird communities in unburned forests are generally made up of a larger proportion of secondary cavity-nesters (e.g., Sedgwick and Knopf 1992). Secondary cavity-nesting birds are often thought to be limited by the availability of nest sites (Brush 1983, Brawn and Balda 1988, Walankiewicz 1991). In this study, over 80% of secondary cavity-nesting bird nests were in cavities obviously excavated by woodpeckers, indicating a strong reliance on primary cavity-nesting birds for cavity excavation. The initial density of primary cavity-nesting birds in an area will obviously influence future cavity availability; the more primary cavity-nesting birds there are in an area, the more cavities that will become available for secondary cavity-nesting birds over time.

Primary cavity-nesting birds may create roost cavities in salvage-logged areas in the winter. Additionally, any large snags left behind during salvage-logging were likely long-dead and partially decayed, and may have contained natural or excavated cavities that were created before the burn. Both of these sources could provide cavities for secondary cavity-nesting birds in salvage-logged areas in the absence of breeding primary cavity-nesting birds.

The rate of cavity re-use on this study area was low. Only a third of active cavities were re-used over the three years of this study. Re-use rates were higher in salvage-logged plots than in unlogged plots, possibly because salvage-logged areas had fewer cavities available for nesting. In unlogged areas, the continuous creation of roosting and nesting cavities by primary cavity-nesting species may provide abundant

new cavities for secondary cavity-nesting birds to use. In contrast, fewer breeding primary cavity-nesting birds in salvage-logged areas create fewer new cavities, and this may force secondary cavity-nesting birds to re-use a smaller number of older cavities.

Several researchers have hypothesized that the abundance of suitable nests sites could limit the density of cavity-nesting birds, especially for non-excavating species (Brush 1983, Brawn and Balda 1988, Walankiewicz 1991). This does not appear to be the case on this study area, as half of the cavities known to be excavated by primary cavity-nesting birds were left unused in subsequent years. Only 6% of cavities found the first year were used for the two following years. In addition, many cavities that appeared to be suitable for nesting were found during the study but were never used by cavity-nesting birds. Studies that use counts of cavities to estimate potential nesting habitat for cavity-nesting birds may be misleading (e.g., Welsh and Capen 1992), since occupancy rates of apparently suitable cavities may be low.

The abundance of nesting sites does not appear to limit secondary cavity-nesting birds on this study areas. There is either something else limiting the density of secondary cavity-nesting birds on this study area, or many of the apparently suitable nesting cavities are not really suitable at all. Other animals [e.g., Northern flying squirrel (*Glaucomys sabrinus*) and Red squirrel (*Tamiasciurus hudsonicus*)] were observed using previously active nest cavities, and may displace or depredate cavity-nesting bird nests. The location of cavities near other nesting individuals of the same or different species may make cavities unsuitable for nesting. For example, cavities located near American Kestrel nests may experience higher rates of predation, as American Kestrels were observed predators

on other cavity-nesting species in this study. Since American Kestrels nested in both salvage-logged and unlogged areas, their presence could be a deterrent to secondary cavity-nesting birds. Other predators known to be on the study area that could affect cavity suitability include skunk (*Mephitis mephitis*), black bear (*Ursus americanus*), and mustelids (*Mustela* spp.). Other factors like reductions in foraging opportunities could also limit secondary cavity-nesting bird density in spite of abundant nesting cavities.

Cavities made by a wide variety of primary cavity-nesters were used in subsequent years, although there was differential use of cavities created by the various primary cavity-nesting species. Hairy Woodpecker cavities appear to be especially suitable for reuse, as 67% of Hairy Woodpecker cavities were reused in subsequent years. A high proportion of Three-toed and Black-backed woodpecker holes were also used for nesting by other species. Excluding cavities created by Northern Flickers, these three species combined provided almost three quarters of the cavities that were reused in subsequent years (Table 8).

Northern Flickers made a substantial contribution toward cavities that were reused, but they also reused most (70%) of those holes themselves (Table 7). Despite using their own holes at such a high rate, Northern Flickers provided more holes for other species of secondary cavity-nesting bird than any other primary cavity-nesting species. Additionally, cavities created by Northern Flickers appeared to be the only excavated cavities suitable for American Kestrels, possibly because of their large body sizes. House Wrens did not use any Northern Flicker cavity, possibly because the entrance hole was too large. Access by predators may be an important driving force in cavity choice.

The cavity-nesting bird community was clearly affected by salvage-logging on this study area in the years following stand-replacement fire. Especially noteworthy was the disappearance of several woodpecker species from salvage-logged areas and the general decrease in nesting density compared to unlogged, burned areas. Mitigation of salvage-logging practices to allow for a diverse cavity-nesting bird community should be a top management priority. Research on the effects of different salvage-logging prescriptions (e.g., leaving more snags across the landscape, leaving patches of unlogged trees scattered through cutting units) is needed.

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Table 1. Summary of vegetation characteristics in unlogged and salvage-logged plots. Mean (SE) listed for numerical variables, frequency distributions for categorical variables. Asterisks indicate significant difference between treatments (Mann Whitney U tests with Bonferonni adjustment, $p < 0.05$).

Vegetation Characteristic	Unlogged (n=132)	Salvage-logged (n=112)
DBH (cm)*	30.7 (1.13)	20.9 (0.93)
Height (m)*	16.2 (0.44)	12.7 (0.39)
% Bark*	97.2 (0.81)	94.0 (1.32)
Tree Species		
<i>lodgepole pine</i>	1.5%	
<i>ponderosa pine</i>	30.3%	18.8%
<i>western larch</i>	9.8%	15.2%
<i>Douglas fir</i>	53.0%	63.4%
<i>deciduous spp.</i>	5.3%	2.7%
Tree Status*		
<i>Intact Snag</i>	74.0%	87.5%
<i>Broken Snag</i>	4.6%	5.4%
<i>Broken Live</i>		0.9%
<i>Live</i>	21.4%	6.3%
Tree Density (15-m radius)		
<i>10-40 cm dbh*</i>	23.7 (1.41)	9.1 (0.75)
<i>>40 cm dbh*</i>	1.6 (0.17)	0.03 (0.02)
% Bare Ground	8.8 (1.00)	8.2 (0.52)
% Ground Cover	33.3 (1.73)	35.4 (1.99)
% Low Shrub	55.5 (1.90)	54.5 (2.01)
% Tall Shrub	2.6 (2.88)	1.6 (0.31)
Burn Severity*		
<i>>60% Green</i>	17.6%	1.8%
<i>40-60% Green</i>	5.3%	2.7%
<i><40% Green</i>	25.2%	8.9%
<i>No green, needles</i>	24.4%	25.0%
<i>No needles, branches</i>	27.5%	61.6%

Table 2. Percent of nests found by different methods of identification, and nest status at the time they were found for cavity nests in unlogged and salvage-logged burned forest.

Method of Identification (n=300)	Percent of nests	
	Unlogged	Salvage-logged
Finding cavity	57.7	47.9
Following adult bird to nest	21.1	23.3
Seeing/hearing adult/young at nest	21.1	28.8
Nest Status (n=392)		
Building/excavating/advertising	17.3	18.4
Incubating	32.0	42.9
Feeding young	50.7	38.8

Table 3. Number of cavity nests by year, with totals divided among new nests, re-used nests (nests in cavities used in previous census years by either same or different species), and repeat nests (nests in cavities used previously in the same breeding season, by the same or different species).

Year	Unlogged			Salvage-logged			Total
	New Nests	Re-used Nests	Repeat Nests	New Nests	Re-used Nests	Repeat Nests	
1993	96	--	--	26	--	--	122
1994	108	29	0	33	13	0	183
1995	108	68	5	46	26	5	258
Total	312	97	5	105	39	5	563

Table 4. Cavity-nesting bird species found nesting in three years of nest censuses in post-fire habitat.

Species	Scientific Name	Abbr.	Nest Type ^a	Foraging Guild ^b
American Kestrel	<i>Falco sparverius</i>	AMKE	2°	GBF
Northern Flicker	<i>Colaptes auratus</i>	NOFL	1°	GBF
Lewis' Woodpecker	<i>Melanerpes lewis</i>	LEWO	1°	AI
Williamson's Sapsucker	<i>Sphyrapicus thyroideus</i>	WISA	1°	TD
Red-naped Sapsucker	<i>Sphyrapicus nuchalis</i>	RNSA	1°	TD
Downy Woodpecker	<i>Picoides pubescens</i>	DOWO	1°	TD
Hairy Woodpecker	<i>Picoides villosus</i>	HAWO	1°	TD
Three-toed Woodpecker	<i>Picoides tridactylus</i>	TTWO	1°	TD
Black-backed Woodpecker	<i>Picoides arcticus</i>	BBWO	1°	TD
Tree Swallow	<i>Tachycineta bicolor</i>	TRSW	2°	AI
Black-capped Chickadee	<i>Parus atricapillus</i>	BCCH	2°	TFS
Mountain Chickadee	<i>Parus gambeli</i>	MOCH	2°	TFS
White-breasted Nuthatch	<i>Sitta carolinensis</i>	WBNU	2°	TG
Red-breasted Nuthatch	<i>Sitta canadensis</i>	RBNU	2°	TG
House Wren	<i>Troglodytes aedon</i>	HOWR	2°	GBF
Western Bluebird	<i>Sialia mexicana</i>	WEBL	2°	GBF
Mountain Bluebird	<i>Sialia currucoides</i>	MOBL	2°	GBF
European Starling	<i>Sturnus vulgaris</i>	EUST	2°	GBF

^a 1° = primary cavity-nesting bird, 2° = secondary cavity-nesting bird. Adapted from Ehrlich et al. 1988.

^b GBF=ground-brush forager, TD=timber driller, AI=aerial insectivore, TFS=timber foliage searcher, TG=timber gleaner. Adapted from Bock and Lynch (1970).

Table 5. Abundance of cavity nests over three years and mean density (# nests/40 ha) over all plots and all years. Values for two standard errors in parentheses. P-values are for Mann-Whitney U tests for differences in mean density between the two treatments. Species abbreviations listed in Table 4.

Species	Unlogged		Salvage-logged		p
	Total # Nests	Mean Density	Total # Nests	Mean Density	
AMKE	6	0.69 (0.24)	5	0.42 (0.16)	0.53
NOFL	81	7.83 (1.74)	51	4.88 (0.72)	0.43
LEWO	2	0.23 (0.23)	0	0	0.35
WISA	9	0.48 (0.20)	0	0	0.07
RNSA	11	0.51 (0.23)	0	0	0.03
DOWO	4	0.41 (0.18)	0	0	0.03
HAWO	15	1.51 (0.39)	5	0.61 (0.25)	0.07
TTWO	9	0.79 (0.29)	0	0	<0.01
BBWO	10	0.91 (0.30)	0	0	<0.01
TRSW	27	2.81 (1.06)	5	0.39 (0.18)	0.05
BCCH	1	0.06 (0.06)	1	0.08 (0.08)	0.90
MOCH	10	0.75 (0.30)	0	0	0.01
WBNU	6	0.37 (0.19)	0	0	0.05
RBNU	8	0.30 (0.12)	0	0	0.03
HOWR	126	11.54 (2.72)	43	4.61 (0.75)	0.24
WEBL	2	0.23 (0.16)	0	0	0.18
MOBL	70	7.10 (1.04)	29	2.63 (0.55)	<0.01
EUST	17	2.06 (0.83)	10	0.84 (0.35)	0.52
TOTAL	414	38.58 (6.25)	149	14.57 (2.07)	<0.01

Table 6. The number of species, density (mean # nests/40 ha +/- 2SE), and percent of total nests for primary and secondary cavity-nesting bird nests in the two treatments. Nesting types listed in Table 4.

Nesting Type		Unlogged	Salvage-logged
Primary	# Species:	8	2
	Density:	12.7 (1.93)	5.6 (0.85)
	Percent of nests:	34.1	37.3
Secondary	# Species:	10	6
	Density:	25.9 (4.64)	9.0 (1.39)
	Percent of nests:	64.9	62.7

Table 7. Re-use of cavities first occupied and excavated by primary cavity-nesting birds by other species of cavity-nesting birds (both primary and secondary species) in years following initial cavity excavation. Bird species abbreviations given in Table 4.

1° CNB Species ^a	# Cavities re-used by different species of cavity-nesting birds									Number of cavities re- used	Total # cavities excavated	Percent Re-used	Percent re- used by <i>different</i> species	Number of cavities. used all 3 years
	AM KE	NO FL	WI SA	RN SA	TR SW	HO WR	WB NU	MO BL	EU ST					
NOFL	3	22			2			2	2	31	73	42%	29%	7
LEWO		1								1	2	50%	100%	0
HAWO		3				3		2		8	12	67%	100%	2
WISA		1			1					2	8	25%	100%	0
RNSA			2	2						4	11	36%	50%	0
BBWO		2				2	1	1		6	12	50%	100%	1
TTWO						1		4	1	6	10	60%	100%	2
Total	3	29	2	2	3	6	1	9	3	58	128	48%	35%	12
%	5.2	50.0	3.4	3.4	5.2	10.3	1.7	15.5	5.2					

^a Species that originally excavated cavity

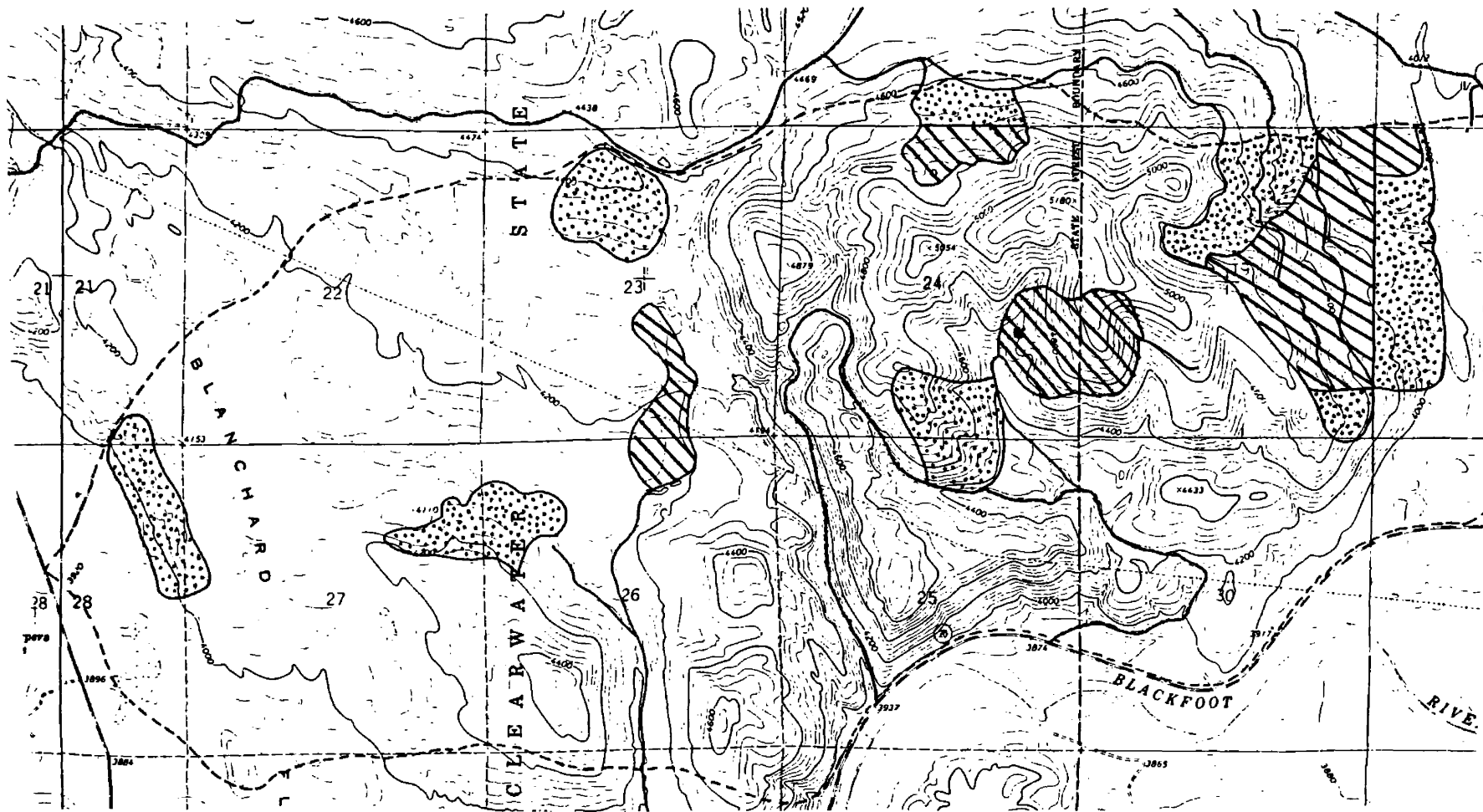


Figure 1. Map of the study plots on the Blackfoot-Clearwater Game Range. The fire boundary is indicated by the dashed line. Stippled areas are unlogged plots and lined areas are salvage-logged plots. Much of the area between plots is grassland.

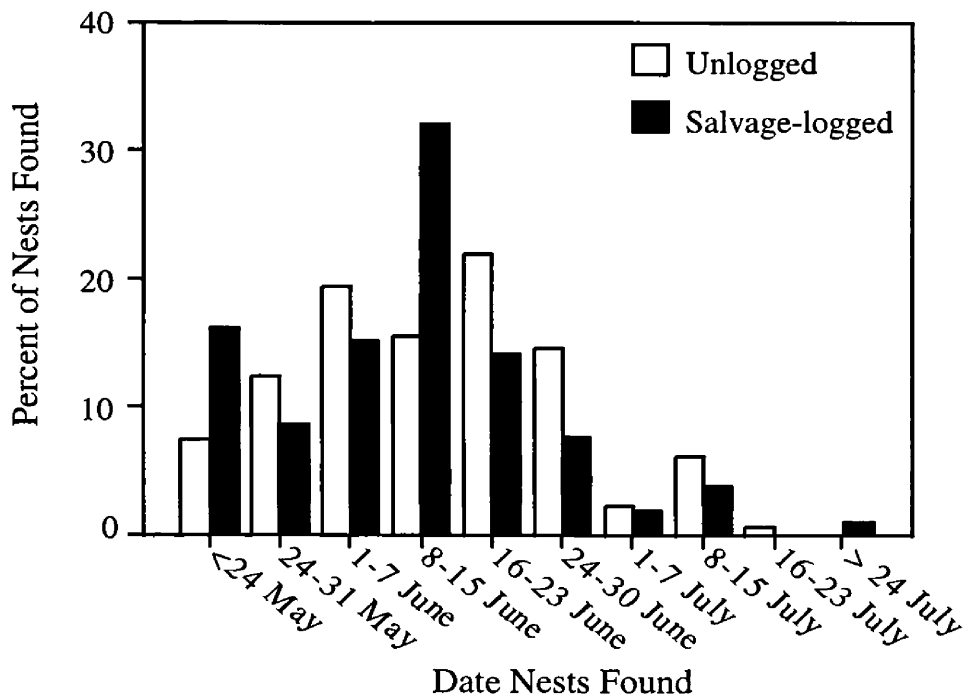


Figure 2. Dates when nests were found over all three years of study (n=416).

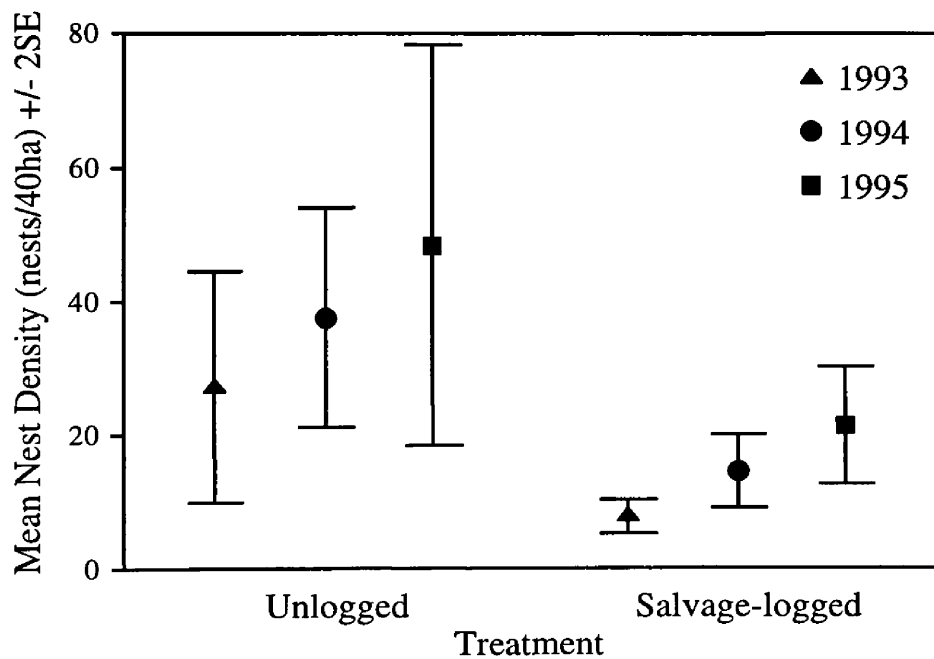


Figure 3. Mean nest density of all species averaged over all plots for each treatment (Repeated measures ANOVA, treatment effect $p=0.015$, year effect $p=0.024$).

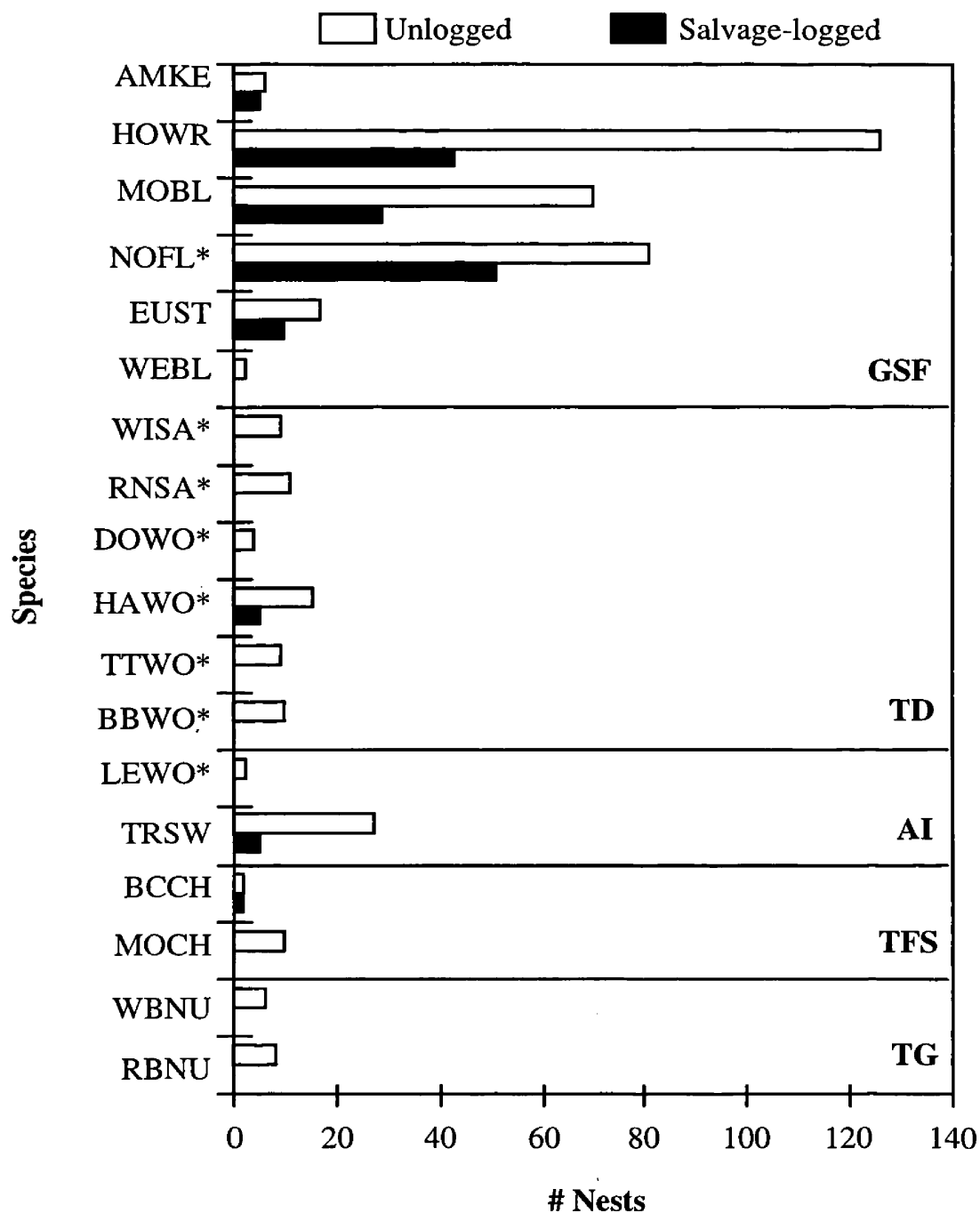


Figure 4. Total nest abundance over all three years for 18 species found in study area, grouped by feeding guilds (X^2 Likelihood Ratio, $p < 0.05$). Bird species and guild abbreviations given in Table 4. Asterisks indicate primary cavity-nesting species.

CHAPTER II

HABITAT CHARACTERISTICS OF CAVITY-NESTING BIRD NESTS IN SALVAGE-LOGGED AND UNLOGGED BURNED FOREST

Introduction

Infrequent, high-intensity, stand-replacement fires were typical of the higher-elevation mixed-conifer forests of the northwestern United States Rocky Mountains prior to European settlement (Arno 1980, Fischer and Bradley 1987). Stand-replacement fires burned unevenly over the landscape, leaving a mosaic of forest patches with low to high burn severities (Turner and Romme 1994) and increasing vegetative diversity in terms of species composition and stand structure (Arno 1980).

Many bird species respond positively to changes associated with fire (Caton 1996). Bird communities in early post-fire habitat are generally more diverse than in unburned habitat, due in part to changes in vegetation (Raphael et al. 1987) and to an increase in the diversity of food available (Apfelbaum and Haney 1981). Insect populations generally increase after fires, and create an abundant food source for a wide variety of insect-eating birds (e.g., aerial insectivores, ground foragers, timber drillers) (Apfelbaum and Haney 1987). The abundance of snags, or standing dead trees, after a fire provide both foraging and nesting opportunities for many species of birds, especially cavity-nesting birds (Bock and Lynch 1970, Taylor 1973, Bock et al. 1978, Raphael et al. 1987, Apfelbaum and Haney 1987, Caton 1996). Over the long term, fire maintains early

seral species like aspen, which are preferred nesting trees for many cavity-nesting bird species (Winternitz and Cahn 1983, Li and Martin 1991, Caton 1996).

Bird community composition in early post-fire sites is unique; a review of 309 studies of bird communities in 15 major vegetation cover types in the northern U.S. Rocky Mountains (Hutto 1995a) found that at least 15 species were more abundant in early post-fire habitats than in any other major cover type. Species like Black-backed Woodpeckers may have evolved specifically in association with burned areas, as evidenced by the fact that they are nearly restricted to recently burned areas in the northwestern U.S. Rocky Mountains (Hutto 1995b).

Unfortunately, both the number and size of high-intensity, stand-replacement fires have decreased dramatically over the past 100 years, due mainly to fire suppression. Wildfires in the northern region of U.S. Forest Service land burned over 1.8 million ha from 1910 to 1919; in contrast, between 1950 and 1959, only 14,500 ha burned (Leege 1968). Pre-settlement stand replacement fires (prior to 1935) in the Selway-Bitterroot Wilderness in western Montana burned about 4,290 ha each year. In contrast, recent fires (1979-1990) in the same area averaged only 2,780 ha annually (Brown et al. 1994). The general public opinion of fires as “negative and destructive” (Habeck and Mutch 1973) has guided the policy of fire suppression.

Of those few stand-replacement fires that do burn on today’s landscape, the resulting burned forests are often salvage-logged almost immediately for their economic value. Again, the general viewpoint of fires as destructive (Hutto 1995a) plays a major role in shaping public policies on salvage-logging. Salvage-logging operations after fires

follow less stringent guidelines than are generally accepted for timber sales in unburned forests (Beschta et al. 1995). In addition, the current federal salvage-logging rider in effect for the remainder of 1996 exempts salvage-logging on public lands from any kind of public review. These guidelines are followed despite the fact that traditional salvage-logging operations cause severe soil disturbance and erosion (Klock 1975), and that there is no published evidence of benefits for any wildlife from this type of land management activity.

Salvage-logging usually removes the one element (standing dead trees) that is likely the most critical element for cavity-nesting birds, yet there are very few published data on the impact of salvage-logging on breeding cavity-nesting birds. The studies that have been done are generally either single-plot or single-transect studies, and most have focused on non-breeding birds. Blake (1982) surveyed cavity-nesting birds during the non-breeding season in burned and unburned ponderosa pine (*Pinus ponderosa*) forests in Arizona. Within a burned area, he surveyed three plots: unlogged, partially salvage-logged, and clearcut salvage-logged. The clearcut salvage-logged plot had the fewest numbers and species of cavity-nesting birds throughout the non-breeding season. Lyon and Marzluff (1984) conducted post-breeding surveys in two areas of a burned forest in northwestern Montana before and after salvage-logging and found a decrease in cavity-nesting bird abundance after salvage-logging. Raphael and White (1984) reported a 77% decrease in cavity-nesting birds following post-fire snag removal on one plot in the Sierra Nevada of California. Harris (1982) found fewer cavity-nesting bird species and lower densities along five transects through two burned areas in northwestern Montana. In one

of the only other studies of breeding cavity-nesting birds in post-fire habitats, Caton (1996) found higher species diversity and abundance of cavity-nesting bird nests in burned, mixed-coniferous forests in Glacier National Park than in either high or low intensity salvage-logged sites on the neighboring Flathead National Forest.

Nest census data from a recent burn in northwestern Montana (Chapter I) showed consistently more cavity-nesting bird nests in unlogged compared to salvage-logged areas. Several species (e.g., Three-toed Woodpecker, Black-backed Woodpecker, Red-naped Sapsucker) were absent from salvage-logged areas while other species (e.g., American Kestrel, Northern Flicker, House Wren) nested in both areas, but were more abundant in unlogged areas.

Why were some species absent from salvage-logged areas? Why were others nesting there, but in lower densities compared to unlogged areas? One hypothesis to explain the observed patterns of nest abundance is that suitable nesting habitat is either reduced or lacking in salvage-logged areas. There is obviously a major physical change in the forest after salvage-logging due to the removal of trees, especially the selective removal of larger snags thought to be valuable to wildlife (Thomas et al. 1979). Appropriate nesting habitat could be lacking in areas where too many trees are removed during salvage-logging operations.

This paper attempts to address whether nest-sites are more limited in salvage-logged areas by asking two main questions about nest trees and nest microsites (the area immediately around the nest tree):

1. What types of trees and microsites are used by cavity-nesting birds for nesting in unlogged and salvage-logged areas? For species that nest in both treatments, are the trees and microsites they use different?
2. By comparing the characteristics of randomly selected trees and microsites in the two treatments to trees and microsites that were used by cavity-nesting birds for nesting, I assessed suitability of potential nesting habitat in the two treatments. Can the pattern of nest abundance observed between salvage-logged and unlogged areas then be explained by differences in the number of suitable nesting sites in the two treatments? If the absence or lower abundance of bird species in salvage-logged areas results from a decrease in the amount of suitable nesting habitat, then the proportion of randomly selected trees and surrounding microsites that are classified as suitable should be lower in salvage-logged compared to unlogged sites.

Methods

Study Area

This study took place on the Blackfoot-Clearwater Wildlife Management Area, which is located about 80 km east of Missoula, MT. Elevation of the study area is between 1200 and 1500 m. A severe fire in October of 1991 burned approximately 1600 ha of grassland and mixed-conifer forest. Approximately 500 ha of timber was salvage-logged in the winter following the fire (1991-1992) in a design that created an interspersed pattern of harvest treatments with unlogged control plots (Figure 1, Chapter I). Both unlogged and salvage-logged forested areas were separated by grasslands. The

burned forested areas consisted mainly of 50 to 150-year-old second-growth conifers [Douglas fir (*Psuedotsuga menziesii*), western larch (*Larix occidentalis*), and ponderosa pine (*Pinus ponderosa*)] with occasional pockets of broad-leaved deciduous trees (*Populus* spp.).

Eight unlogged plots (totaling approximately 148 ha) and seven salvage-logged plots (totaling approximately 134 ha) ranging in size from 7 to 34 ha each were selected for this study (Figure 1, Chapter I). Plots were delineated in part based on timber harvest prescriptions provided by logging companies. The extent of salvage-logging varied among plots, but in most cases all merchantable (>15 cm dbh, >4.5 m tall), fire-killed timber was removed from salvage-logged plots.

Habitat Measurements

Active cavity nests were located by searching these 15 forest plots during the breeding season from mid- May through mid-July of 1993, 1994 and 1995 (see Chapter I). During the 1993 field season, characteristics of nest trees and nest microsites (the area within a 15-m-radius circle around the nest tree) were measured at the time the nest was found. Tree size (diameter at breast height) was measured with a dbh tape, and tree height was measured with a clinometer. Tree species and the status of the tree (live or dead; intact, bent, or with a broken or dead top) was recorded. The percent of bark remaining on the tree was estimated visually. To assess microsite characteristics, stakes were placed 15 m from the tree in the four cardinal directions. Ocular estimates of the percent of bare ground (bare soil), ground cover (herbaceous plants <25 cm tall), low shrub (herbaceous plants >25 cm tall plus woody plants <0.5 m), and tall shrub (woody

plants > 0.5 m tall) were made in each quarter and then averaged for the nest microsite.

These estimates were made from a “birds-eye” perspective (i.e., only the top layer was estimated so the four estimates sum to 100%). Burn severity of the microsite canopy was rated on a subjective scale of one to six, 1) 100% green, 2) 40-60% green, 3) <40% green, 4) no green but brown needles, 5) no brown needles but some twigs, and 6) no twigs but some branches.

During the 1994 and 1995 field seasons, vegetation measurements were taken with the same protocol after the breeding season. In 1995, habitat characteristics were also measured at 244 randomly selected trees. Unlogged plots totaled slightly more area than salvage-logged plots (148 vs. 134 ha), so in order to sample the same number of trees per ha, slightly more random trees were selected in unlogged sites (132 vs. 112). Random trees were identified by locating random grid points on high resolution aerial photos (scale: 1 inch = 100 feet). If a grid point fell on a tree, that tree was selected as a random tree. Otherwise the point was discarded. Grid points were repeated until all random trees had been identified. Random trees were located on the ground with the aid of the aerial photos. In addition to the habitat characteristics described above for nest trees and associated microsites, I also counted the number of recently cut stumps and old cut stumps (cut before the fire) in a 15-m-radius circle around each tree.

Analysis of Tree and Microsite Characteristics

Habitat analysis was limited to species with nine or more nests. Characteristics of nest trees and associated microsites were summarized for each species, and were compared to characteristics of randomly selected trees and microsites in unlogged and

salvage-logged areas. Differences in numerical variables were tested with Mann-Whitney U tests, and differences in distributions of categorical variables were tested with the Chi-Square Likelihood ratio. A Bonferonni correction for experiment-wise error was applied to all univariate tests for each species (correction for 13 simultaneous tests, for $\alpha > 0.95$, $p < 0.0038$, and for $\alpha > 0.99$, $p < 0.0008$). When the same bird species nested in the same cavity in two or more years, the habitat characteristics at that nest tree were only included once in the analysis. For species with large sample sizes ($n > 20$ in each treatment), nest trees and associated microsites were also compared between salvage-logged and unlogged sites. Logistic regression was used for these species to identify the most important habitat variables that combined to account for differences between nesting habitat in salvage-logged and unlogged areas.

Analysis of Suitability

The suitability of random trees and associated microsites for each species of cavity-nesting bird was assessed by first calculating the range of habitat characteristics at used nest trees and associated microsites. If the value of a habitat characteristic associated with a random tree or its surrounding microsite fell within the range of values obtained for used nest trees and microsites, that random tree or microsite was considered suitable for that characteristic. Therefore, each habitat characteristic potentially eliminated some proportion of random trees or microsites as suitable. Habitat characteristics that had smaller ranges obviously eliminated a larger proportion of random

trees or microsites. The habitat characteristics that eliminated the most random trees as suitable were assumed to be most limiting.

Overall suitability was determined by combining suitability information from all the individual tree and microsite habitat characteristics. If values from all tree characteristics of a random tree fell within the range of values from used nest trees, that random tree was considered suitable for that species. Similarly, if values from all habitat characteristics of a random microsite fell within the range of values from used microsites, that random microsite was considered suitable. A combined random tree and associated microsite was considered suitable if each was considered suitable on its own. The proportion of random trees and/or microsites classified as suitable for each species was converted into an absolute measure of suitable trees/ha.

Results

Characteristics of Nest Trees and Associated Microsites

Species limited to nesting in unlogged areas.

Black-backed Woodpeckers - Tree characteristics measured at Black-backed Woodpecker nest trees were not different from those at random trees in unlogged areas, although nest trees were larger in diameter than randomly selected trees in salvage-logged areas (Figure 5). Tree density in the microsite around nest trees was higher than in randomly-selected microsites in salvage-logged areas (Figure 7), and the percent of tall shrub cover was significantly lower than around random trees in either area (Figure 8).

Three-toed Woodpecker - Three-toed Woodpeckers nested in larger and taller trees than what was randomly available in salvage-logged areas (Figure 5), and nested in western larch more often than expected compared to random trees in either salvage-logged or unlogged areas (Figure 6). Nest microsites had more surrounding trees and were less severely burned compared to random microsites in salvage-logged areas (Figure 7). Nest microsites had more bare ground and less low shrub cover than microsites in either salvage-logged or unlogged areas (Figure 8).

Red-naped Sapsucker - Red-naped Sapsucker nest trees were larger than randomly selected trees in salvage-logged areas (Figure 5). They used deciduous trees exclusively for nesting, and used live trees more often than expected based on the availability of live trees in either salvage-logged or unlogged areas (Figure 6). Microsites around Red-naped Sapsucker nest trees had more trees and were less severely burned than expected compared to random microsites in either treatment type (Figure 7). Nest microsites had less bare ground than random microsites in either unlogged or salvage-logged areas (Figure 8).

Williamson's Sapsucker - Nest trees were larger and taller than randomly selected trees in salvage-logged areas (Figure 5). Williamson's Sapsuckers used deciduous trees more often than expected for nesting, but they also nested in several other tree species (Figure 6). Density of large-diameter trees was higher around nest microsites than random microsites in salvage-logged areas (Figure 7). Nest microsites had more bare ground than microsites around random trees in salvage-logged areas (Figure 8).

Mountain Chickadee - Mountain Chickadee nest trees were shorter and had less bark than randomly selected trees in unlogged areas (Figure 5). They used broken-topped snags more often than expected in either area (Figure 6). Microsites around nests had more trees and were less severely burned compared to random microsites in salvage-logged areas (Figure 7).

Species nesting in both unlogged and salvage-logged areas: The first four species listed below (American Kestrel, Tree Swallow, European Starling, Hairy Woodpecker) nested in such low numbers that comparisons of characteristics of nest trees between salvage-logged and unlogged areas were not made. All nests in the two treatments for each of these four species were combined in order to summarize nest habitat characteristics. The remaining three species (House Wren, Northern Flicker, and Mountain Bluebird) nested in high enough numbers in both treatments that in addition to comparisons between nests and random trees, nests in the two treatments were compared.

American Kestrel - American Kestrels nested in significantly larger snags (Figure 5) that had broken tops more often than expected compared to random trees in either unlogged or salvage-logged areas (Figure 6). Large tree density in nest microsites was significantly higher compared to random microsites in salvage-logged areas (Figure 7).

European Starling - Nest trees were larger than random trees in salvage-logged areas and had less bark than random trees in unlogged areas (Figure 5). European Starlings nested in deciduous snags more often than expected based on comparisons with random trees in either salvage-logged or unlogged areas (Figure 6). Tree density in nest microsites was higher than in random microsites in salvage-logged areas (Figure 7). Nest

microsites had less bare ground and ground cover than microsites in salvage-logged areas (Figure 8). Nest microsites had less ground cover but more low shrub cover than random microsites in unlogged areas (Figure 8).

Tree Swallow – Nest trees were larger than random trees in salvage-logged areas, and had less bark than random trees in unlogged areas (Figure 5). Tree Swallows nested in deciduous, broken-topped snags more often than expected compared to random trees in either area (Figure 6). Nest microsites had more trees than random microsites in either treatment, and tended to be less severely burned (Figure 7). Nest microsites also had less bare ground than random microsites in either area, and had more tall shrub cover than random microsites in salvage-logged areas (Figure 8).

Hairy Woodpecker – Hairy Woodpeckers nested in trees that were larger, taller, and had less bark than randomly selected trees in salvage-logged areas (Figure 5). They used intact snags more often than expected in unlogged areas (Figure 6). Nest microsites had more trees than random microsites in salvage-logged areas (Figure 7).

House Wren – Univariate comparisons revealed no differences in characteristics of House Wren nest trees in salvage-logged vs. unlogged areas (Table 8). The microsites surrounding nest trees were slightly different, however, in that nest microsites in salvage-logged areas had fewer trees and more bare ground compared to those in unlogged areas (Table 8). Percent bark and tree density were the two main characteristics that discriminated nests in salvage-logged from those in unlogged areas (multiple logistic regression, $p < 0.05$).

Combining all House Wren nests together, nest trees were larger than random trees in salvage-logged areas, and were shorter and had less bark than random trees in unlogged areas (Figure 5). Broken snags and aspen were used more often than expected based on their availability in either area (Figure 6). Nest microsites were less severely burned than random microsites in salvage-logged areas, but more severely burned than random microsites in unlogged areas. Nest microsites also had higher densities of all tree sizes than random microsites in salvage-logged areas, but actually had fewer large trees than in random microsites in unlogged areas (Figure 7). Nest microsites had less bare ground than random microsites in either area (Figure 8). Tree species and tree status were the main variables distinguishing nests from random trees in both unlogged and salvage-logged areas (multiple logistic regression, $p < 0.05$). Additionally, tree size and tree density were important variables in distinguishing nests from random trees in salvage-logged areas (multiple logistic regression, $p < 0.05$).

Mountain Bluebird – Nests in unlogged areas were in taller trees that had more bark compared to nests in salvage-logged areas (Table 8). Nest microsites in unlogged areas had higher tree densities compared to microsites in salvage-logged areas. Tree density was the only significant characteristic discriminating nests in salvage-logged from those in unlogged areas (multiple logistic regression, $p < 0.05$).

Grouping data from all Mountain Bluebird nests together, nest trees were larger in diameter than random trees in salvage-logged areas. Nest trees were also shorter and had less bark compared to random trees in unlogged areas (Figure 5). Mountain Bluebirds used western larch, deciduous trees, and broken snags for nesting more often than

expected based on the availability of these trees in either unlogged or salvage-logged areas (Figure 6). Nest microsites had more trees than random microsites in salvage-logged areas, but actually had fewer large trees than random microsites in unlogged areas (Figure 7). Nest microsites were in more severely burned areas than expected compared to random microsites in unlogged areas.

In unlogged areas, tree status, tree species and percent bark were the main variables contributing to differences between nests and randomly selected trees (multiple logistic regression, $p < 0.05$); however, the correct classification of nest trees was poor (46%). In salvage-logged areas, tree status and tree species were the only variables contributing to differences between nests and randomly selected trees (multiple logistic regression, $p < 0.05$). The correct classification rate for nest trees (77%) was somewhat higher than for comparison with random trees in salvage-logged areas.

Northern Flicker - Northern Flicker nests in unlogged areas were in taller trees, and were distributed differently among tree species and tree status types compared to nests in salvage-logged areas (Table 8). The only difference between nest microsites in the two areas was tree density (Table 8). Tree density, burn severity and tree height were the main habitat characteristics contributing to differences between nest trees in the two areas (multiple logistic regression, $p < 0.05$).

Grouping all Northern Flicker nests together, nest trees were larger and had less bark than random trees in either area (Figure 5). Nest trees were also significantly shorter than random trees in unlogged areas. Northern Flicker nests were in deciduous trees and

broken snags more often than expected based on the availability of those trees in either area (Figure 6).

Nest microsites were less severely burned than expected compared to random microsites in salvage-logged areas (Figure 7). Tree density around nest trees was also higher than around random trees in salvage-logged areas, but, in the smaller size class, was actually lower than around random trees in unlogged areas (Figure 7).

Tree size, height, status, species and microsite burn severity all contributed significantly to differences between nest trees and random trees in unlogged areas (multiple logistic regression, $p < 0.05$). These same variables, plus tree density, also distinguished nests from random trees in salvage-logged areas (multiple logistic regression, $p < 0.05$).

Availability of Suitable Habitat

Differences in characteristics of random trees in unlogged compared to salvage-logged areas indicated likely differences in suitability of the two habitats for cavity-nesting birds. Random trees in unlogged areas were significantly larger and taller, and also had more bark than random trees in salvage-logged areas (Figure 5). Live trees made up a much larger proportion of the sample in unlogged (21%) compared to salvage-logged areas (6%), and there was a higher proportion of intact snags in salvage-logged areas (Figure 6). Tree density in random microsites was significantly higher in unlogged areas in all size classes (Figure 7). Microsites were more severely burned in salvage-logged areas (Figure 7). Density of both old and new stumps in random microsites was significantly higher in unlogged areas. Microsites in unlogged areas contained an average

of 0.4 newly cut and 1.3 old cut stumps, whereas microsites in salvage-logged areas averaged 9.7 newly cut and 4.5 old cut stumps. Tree size, tree density, newly-cut stump density, burn severity, and percent of low-shrub cover were all significant variables distinguishing between randomly selected trees in salvage-logged vs. unlogged areas (multiple logistic regression, $p < 0.05$).

Ranges of tree and microsite characteristics at cavity nests used to estimate the amount of suitable habitat available varied widely among species (Appendix). For some species, single habitat characteristics excluded a large number of randomly selected trees from being considered suitable. For example, American Kestrels used such large trees for nesting that 91% of the randomly selected trees in salvage-logged areas were excluded based on this measurement alone (Table 9). Similarly, Red-naped Sapsuckers were limited to nesting only in deciduous trees. Since deciduous trees comprised a small percentage of random trees, the amount of suitable nest tree habitat was reduced to close to zero in both unlogged and salvage-logged areas (Table 9).

The percentage of suitable trees in each treatment was converted to an absolute number of trees per ha by multiplying the percentage by the estimated number of trees per ha in each treatment (360 trees/ha in unlogged areas and 134 trees/ha in salvage-logged). The amount of available nesting habitat (combining microsite and tree suitability) varied from zero for Red-naped Sapsuckers in salvage-logged areas, to over 200 trees/ha for House Wrens and Northern Flickers in unlogged areas (Figure 9).

Discussion

Salvage-logging prescriptions on this study area removed only fire-killed trees, leaving salvage-logged plots with fewer, smaller, shorter snags compared to unlogged plots. Although this type of salvage-logging appears to negatively affect all species of cavity-nesting birds studied (Chapter I), there are several aspects about this type of salvage-logging that likely helped to maintain some species of cavity-nesting birds in salvage-logged plots. One is that many older snags that were already dead before the fire were left behind, unless they posed a safety hazard for loggers. These snags may provide potential nesting habitat for cavity-nesting birds, though their life span may be reduced due to the removal of surrounding trees that may have provided protection from wind (Raphael and Morrison 1987).

Another positive aspect of this type of salvage-logging is that live trees were left behind. However, on this study area, there appeared to be very few live trees in salvage-logged plots, especially compared to unlogged plots. If all plots were burned at the same severity, I expected the opposite to be true: salvage-logged plots would have relatively more live trees, due to the selective removal of fire-killed trees, than unlogged plots. Unfortunately, little is known about what the two treatment areas were like immediately after the fire. The decision of where to salvage timber may have been based in part on where the most severe burn occurred.

The higher density of old cut stumps in salvage-logged areas indicated that there had been more logging prior to the fire in those areas compared to unlogged areas. More roads and better access through previously logged forest may have been another factor

influencing the decision of where to salvage log. Estimates of pre-fire tree density were made in salvage-logged areas by adding stump density to existing tree density. Pre-fire densities of 271 trees/ha in salvage-logged areas were still well below the post-fire tree density in unlogged areas (360 trees/ha) . It is likely that salvage-logged and unlogged areas were somewhat different prior to the onset of fire and subsequent salvage-logging. These factors could affect post-fire nesting bird communities, and would not be obvious in the current study.

There are several recurring themes from the data about suitable nesting habitat for cavity-nesting birds. Five of the 12 species studied here used broad-leaved deciduous trees more often for nesting, even though these trees constituted less than 5% of available trees. Over a third of all nests were in deciduous trees. This finding is similar to other reports by Li and Martin (1991) in unburned forest and by Caton (1996) and Hutto (1995a) in burned forest. In the West, broad-leaved deciduous trees often make up a very small component of mixed-conifer habitat. They are usually not under direct threat from salvage-logging, though they may be damaged or knocked down by nearby logging equipment.

Most species of cavity-nesting bird used snags rather than live trees for nesting. This is not too surprising, since snags were the most abundant nesting substrate throughout the burn. However, several species used broken-topped snags more than expected based on their availability. The wood of broken-topped snags may be softened from fungal infection. Several species of cavity-nesting birds prefer trees infected with fungal rot for cavity excavation (Erskine and McLaren 1972, Harestad and Keisker 1989).

Broken-topped snags tended to be left behind during this salvage-logging operation. However the removal of intact snags from salvage-logged areas may still reduce suitability to those species that would otherwise use them for nesting.

Every species but Mountain Chickadee used nest trees that had significantly larger diameters than random trees in salvage-logged areas. The selective removal of economically valuable larger-diameter trees obviously reduced the average tree size in salvage-logged areas, and subsequently reduced the amount of suitable nesting habitat. Three species nested in trees that were taller than random trees in salvage-logged areas, but surprisingly, four species also nested in trees significantly shorter than random trees in unlogged areas. Shorter nest tree height for these four species is likely a reflection of their use of broken-topped snags.

Seven species nested in trees with less bark coverage compared to random trees in unlogged areas. Most of these species were secondary cavity-nesting birds, and they were likely nesting in softer, more decayed trees than what was randomly available in unlogged areas. For these species, snags created by fire may not be immediately suitable for nesting until later stages of decay.

Three of the cavity-nesting bird species in this study nested in relatively high numbers in both unlogged and salvage-logged areas. Two of these (House Wren and Mountain Bluebird) nested in the same types of trees and basically the same microsites regardless of what treatment they were in. The only recurring difference in nest microsites between the two areas was consistently higher tree density in microsites in unlogged areas. In contrast to those two species, nest trees and associated microsites used

by Northern Flickers were substantially different between unlogged and salvage-logged areas. This appears to be a reflection of the kinds of habitat that are available in the two areas. Northern Flickers exhibit greater flexibility in their nesting habitat than any of the other species examined in this study.

In this study, randomly selected trees and their associated microsites were classified as suitable if their measured habitat characteristics fell within the ranges of measured values used by each species of cavity-nesting bird. This was a liberal classification of what was suitable. In all likelihood, some values of habitat characteristics were used more often than others, and these habitat values may have been better or “more suitable” than others. Using different standards (e.g., one standard deviation to either side of a mean) may be useful as a more conservative estimate of suitability, but was probably not appropriate for this study due to non-normally distributed values and small sample sizes. Developing multivariate methods of defining suitability would be valuable and would likely make more conservative estimates of what habitat is truly suitable. Nonetheless, the current method is useful for relative comparisons between species and between treatments.

Different habitat characteristics clearly limited different species of cavity-nesting birds. For example, American Kestrels were severely restricted to large-diameter trees for nesting habitat. Ninety-one percent of random trees in salvage-logged areas and just over half of random trees in unlogged areas were too small to be considered suitable as nest trees (Table 9). Since Red-naped Sapsuckers only nested in deciduous trees, this habitat characteristic eliminated almost 95% of all trees as suitable (Table 9). Mountain

Chickadees nested in dense-tree microsites, and almost 90% of microsites in salvage-logged areas were classified as unsuitable on this characteristic alone (Table 9).

Comparisons between species revealed differences in breadth of used nesting habitat. For example, Three-toed Woodpeckers appeared to be less specialized than Black-backed Woodpeckers because they used a wider range of both tree sizes and tree heights for nesting. Williamson's Sapsuckers used a wider range of trees species than Red-naped Sapsuckers; they also used a wider range of tree sizes and heights.

The differences in the availability of suitable nesting habitat across species support the hypothesis that the amount of suitable habitat may, in part, explain observed patterns of abundance. However, one problem with this method of assessing suitability is the relationship between sample size and ranges of values. Since the delineation of suitable or not suitable is based on the range of used characteristics, and the range of used characteristics is based on the sample of data collected during the study, it is possible that perceived increases in abundance of suitable habitat merely reflect larger sample sizes for some species. At the same time, larger sample size could simply result from a wider range of characteristics used by a species: species that are more flexible in their nesting requirements will likely be more numerous, and rare species may be rare because they will only use a small range of habitat characteristics. One remedy for this dilemma is to increase sample sizes of rare birds and repeat assessments of suitability. That is beyond the scope of this study. However, I can examine smaller samples from the data collected in this study of habitat characteristics for the more numerous species. For example, 30 repeated small random samples ($n=10$) of tree sizes for Northern Flicker nests taken from

the large sample (n=132) have a mean range size of 55.4 cm dbh, which is still larger than the range exhibited by Black-backed Woodpeckers (20.0 cm) or Three-toed Woodpeckers (31.2 cm). This leads one to suspect that the ranges exhibited by birds in this study are a true reflection of what they use rather than a result of sampling error.

Species like Red-naped Sapsuckers and Three-toed Woodpeckers were clearly limited by the reduction of suitable nesting habitat in both unlogged and salvage-logged areas. Three-toed Woodpeckers appeared to be especially limited by the availability of microsites rather than trees. Other species like Williamson's Sapsuckers and Black-backed Woodpeckers appeared to be less limited by suitable nesting habitat in unlogged compared to salvage-logged areas, as there were more suitable nesting sites for both these species in unlogged areas. Still other species like House Wren, Northern Flicker, and Mountain Bluebird appear to have abundant suitable nesting habitat in both treatment types. Even though suitable habitat is reduced in salvage-logged areas, the availability of between 71 and 122 suitable nesting trees and microsites per ha would seem to be abundant enough to support higher bird densities than what was found.

A key component of nesting for secondary cavity-nesting species like House Wren and Mountain Bluebird is the presence of a nesting cavity in a tree. From observation during this study, these two species were somewhat flexible in their cavity requirements. House Wrens, for example, were observed nesting in cracks in wood and behind loose pieces of bark. The presence of a cavity in a random tree was not used as a habitat characteristic to calculate the amount of suitable nesting habitat. Only three random trees on unlogged plots and only one random tree in salvage-logged plots had what appeared to

be an actual cavity. Obviously, if the presence of a cavity had been a factor in assessing suitability, the amount of suitable habitat for all secondary cavity-nesting species would have been reduced to close to zero. For species like House Wren, however, that are flexible in what they will use as a nesting cavity, excluding trees as suitable based on the absence of a cavity alone would probably exclude some trees that would otherwise be suitable. In reality, secondary-cavity nesting birds are not selecting nest trees from a random sample, but rather are selecting from trees that already have cavities. In that case, nesting sites still do not appear to limit nesting opportunities, as there are abundant cavities that were left unoccupied throughout this study (Chapter I).

This study does not address foraging needs of cavity-nesting birds. Obviously, food is an important resource, and the absence of foraging opportunities amid plentiful nesting habitat would make the availability of nesting habitat meaningless. The three species that were most abundant throughout the study (House Wren, Mountain Bluebird, Northern Flicker) were all relatively “tree-independent” foragers. They forage for insects on shrubs and on the ground, and are not directly dependent on trees. Salvage-logging may actually improve foraging opportunities for members of this guild by allowing increased brush and shrub growth over time. In contrast, the rarer species in this study are all relatively “tree-dependent” foragers. Birds like woodpeckers forage on dead trees for bark beetle larvae. Salvage-logging may reduce foraging opportunities for these birds, which, in turn, could be the primary determinant of habitat suitability (Caton 1996).

Management Implications

Several studies have made recommendations for snag retention during salvage-logging. Raphael (1983) recommended leaving 7 to 15 snags/ha during salvage-logging based on a simulation model of cavity-nesting bird densities. Raphael and White (1984) estimated 423 soft snags (greater than 15 years old) per hectare were required to support maximum densities of cavity-nesting birds on burned forests, and that four fire-killed hard snags were required to create one soft snag over time. Harris (1982) recommended leaving all western larch snags, and as many large snags (>34 cm dbh) as possible. Raphael and White (1984), Harris (1982) and Hutto (1995a) recommended leaving fire-killed snags in clumps rather than leaving isolated snags standing alone during salvage-logging.

The density of snags on the unlogged areas of this burn were well below the number estimated by Raphael and White (1984) for maximum cavity-nesting bird densities. Obviously, density of snags on salvage-logged areas was even lower. The life-span of fire-killed snags is shorter than for snags created by other means (Morrison and Raphael 1993), and viability of post-fire snags as suitable nesting substrate may be brief. This makes the protection and maintenance of early post-fire habitat an even more critical issue.

It is clear that cavity-nesting birds in this study used a wide variety of nesting substrates. Some types of trees used for nesting (e.g., deciduous snags, older decayed snags with broken-tops) were generally not threatened directly by salvage-logging operations. However, the removal of large, fire-killed snags appeared to have an

immediate negative effect on species that would use those types of snags for nesting.

Over the long term, the loss of those snags may be also be detrimental to other birds that would re-use old cavities for nesting.

Although recommendations for leaving snags during salvage-logging based on generalities may meet the needs of some cavity-nesting bird species (e.g., leaving large trees, leaving preferred tree species, etc.), those types of guidelines will not ensure the maintenance of suitable habitat on a community-wide basis. It is clear that the key to maintaining diverse cavity-nesting bird communities is to leave a wide variety of habitat on the landscape, in order to provide nesting habitat for all species of cavity-nesting bird. The elimination of salvage-logging would appear to benefit all species of cavity-nesting birds. It is clear from this and other studies of burned forests that post-fire forests are not “blackened wastelands” but thriving unique ecological communities.

However, economic and political realities often conflict with what are the most ecologically sound management decisions, and salvage-logging of post-fire forests is a reality in the northwestern U.S. Rocky Mountains. Therefore, when salvage-logging occurs, what is the best way to mitigate the loss of habitat for cavity-nesting birds? Harris (1982) and Hutto (1995a) have recommended leaving patches of unlogged forest during salvage-logging operations, rather than leaving isolated trees. By selecting patches of unlogged forest with a wide variety of habitat conditions (e.g., patches of live and deciduous trees intermixed with stands of coniferous snags of various species and sizes), one can increase the chances that a diverse cavity-nesting bird community is maintained. The alternative, trying to figure out how many of each size and species of tree to leave for

each species of cavity-nesting bird, is an impossible task, and would lead to a more uniform, “cookbook”-based environment. Besides, leaving individual trees suitable for nesting in an expanse of salvage-logged stumps does not necessarily guarantee maximum cavity-nesting bird densities, as this study and others have shown. Clumps of undisturbed burned forest may provide more foraging opportunities, especially for timber-drillers, and may provide protection from predators. More research on the effects of salvage-logging on foraging and reproductive success is needed. Information about trees and microsites used by cavity-nesting birds for nesting should be used to identify critical burned forest habitat. Additionally, new experimental strategies for salvage-logging need to be designed and tested for their effects on cavity-nesting birds as well as other wildlife species.

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Table 8. Characteristics of nest trees in unlogged (UL) vs. salvage-logged (SL) plots for three species that nested in high numbers in both treatments. Mean (*SE*) given for numerical data, frequency distributions given for categorical data. Asterisks indicate significant difference ($p < 0.05$) between treatments (Mann Whitney U test for numerical variables and Chi Square Likelihood Ratio for categorical variables; Bonferonni correction for 13 simultaneous tests).

Tree Characteristic	House Wren		Mountain Bluebird		Northern Flicker	
	UL n=110	SL n=31	UL n=58	SL n=23	UL n=69	SL ^a n=39
DBH (cm)	31.1 (2.02)	27.9 (2.72)	29.1 (1.44)	35.3 (3.52)	37.7 (2.29)	36.8 (2.96)
Height (m)	13.3 (0.67)	11.7 (1.28)	14.7 (0.78)	* 10.2 (1.35)	14.2 (0.81)	* 8.6 (1.05)
Percent Bark	89.7 (1.87)	82.3 (4.87)	94.4 (2.03)	* 79.7 (6.07)	91.6 (1.72)	81.7 (4.72)
Tree Species						*
lodgepole pine	0.9%	3.3%		4.8%		
ponderosa pine	9.1%		15.8%	14.3%	27.5%	5.1%
western larch	26.4%	33.3%	38.6%	23.8%	11.6%	12.8%
Douglas fir	28.2%	36.7%	31.6%	33.3%	17.4%	61.5%
deciduous spp.	35.5%	26.7%	14.0%	23.8%	43.5%	20.5%
Tree Status						*
Intact Snag	60.6%	50.0%	65.5%	31.8%	58.0%	30.8%
Broken Snag	30.3%	36.7%	34.5%	54.5%	40.6%	56.4%
Broken Live	0.9%			4.5%	1.4%	2.6%
Bent Snag	6.4%	13.3%		9.1%		10.3%
Live	1.8%					

Table 8. (cont'd)

Microsite Characteristics	House Wren		Mountain Bluebird		Northern Flicker				
	UL	SL	UL	SL	UL	SL ^a			
	n=110	n=31	n=58	n=23	n=69	n=39			
Tree Density									
10 - 40 cm dbh	22.9 (1.44)	* (1.67)	12.0	28.7 (2.75)	* (1.85)	11.7 (1.77)	22.2 (1.77)	* (1.24)	7.9 (1.24)
>40 cm dbh	1.1 (0.23)	0.3 (0.13)	0.9 (0.17)	0.2 (0.11)	1.8 (0.30)	* (0.01)	0.1 (0.01)		
Total >10cm dbh	24.6 (1.43)	* (1.70)	12.8	28.9 (2.53)	* (1.95)	12.8 (1.91)	25.2 (1.91)	* (1.22)	8.5 (1.22)
% Bare Ground	5.2 (0.78)	* (1.03)	7.8	4.9 (0.67)	9.2 (1.50)	8.3 ^s (1.63)	10.4 (1.61)		
% Ground Cover	51.0 (2.38)	49.3 (3.67)	62.0 (3.75)	57.5 (5.74)	55.8 (3.08)	49.9 (3.99)			
% Low Shrub	40.50 (2.33)	38.5 (3.42)	30.2 (3.45)	31.7 (5.69)	33.3 (2.86)	37.1 (4.14)			
% Tall Shrub	4.0 (0.79)	4.4 (1.45)	2.8 (1.13)	1.6 (0.48)	2.6 (0.65)	2.56 (0.48)			
Burn Severity									
1. >60% green			1.7%		2.6%	5.9%			
2. 40-60% green	9.1%		1.7%		2.6%	7.4%			
3. <40% green	28.2%	12.9%	22.4%	13.0%	7.9%	29.4%			
4. No green, brown needles	38.2%	41.9%	39.7%	47.8%	34.2%	33.8%			
5. No needles, some twigs	23.6%	45.2%	34.5%	39.1%	50.0%	23.5%			
6. No twigs, some branches	0.9%				2.6%				

Table 9. The percent of random trees and microsites considered suitable by comparing characteristics to the range of characteristics at used nest trees for each species (sample sizes in parentheses). Values below 25% are highlighted, as these are the characteristics which most reduced the amount of suitable habitat. UL=unlogged, SL=salvage-logged. Species abbreviations given in Table 4.

	BBWO (10)		TTWO (9)		RNSA (10)		WISA (9)		MOCH (10)		AMKE (11)	
Tree Characteristics	UL	SL	UL	SL	UL	SL	UL	SL	UL	SL	UL	SL
DBH	58.3	20.5	72.7	31.3	59.8	25.9	67.4	20.5	52.3	37.5	47.7	8.9
Height	84.8	76.8	66.7	31.3	67.4	69.6	93.2	93.8	79.5	95.5	94.7	96.4
% Bark	97.7	92.8	96.2	92.0	94.7	92.0	94.7	92.0	94.7	92.0	97.7	93.8
Tree Status	100	99.1	100	99.1	94.7	93.8	99.2	99.1	98.5	100	99.2	99.1
Tree Species	97.3	93.2	93.2	97.3	5.3	2.7	68.2	81.3	78.0	92.9	98.5	100
<i>ALL TREE CHARACTERISTICS</i>	<i>47.7</i>	<i>14.3</i>	<i>47.7</i>	<i>10.7</i>	<i>3.0</i>	<i>0</i>	<i>39.4</i>	<i>10.7</i>	<i>35.6</i>	<i>40.9</i>	<i>42.4</i>	<i>7.1</i>
Microsite Characteristics												
Tree density (10-40 cm dbh)	91.7	83.9	68.9	31.3	59.8	56.3	89.4	96.4	63.6	11.6	80.3	92.9
Tree density (>40 cm dbh)	96.2	96.4	75.0	96.4	97.0	96.4	75.0	96.4	62.9	10.7	97.0	96.4
% Bare Ground	100	100	31.1	42.9	78.0	75.0	97.7	100	82.6	79.5	100	100
% Ground Cover	91.7	96.4	74.2	76.8	84.1	85.7	100	100	94.7	98.2	100	100
% Low Shrub	100	100	40.9	35.7	84.8	78.6	100	100	93.9	94.6	83.3	82.1
% Tall Shrub	56.8	67.9	77.3	88.4	100	99.1	100	99.1	77.3	88.4	100	99.1
Burn Severity	76.5	95.5	54.5	36.6	47.7	13.4	72.0	38.4	75.0	75.0	93.9	97.3
<i>ALL MICROSITE CHARACTERISTICS</i>	<i>32.6</i>	<i>36.6</i>	<i>3.8</i>	<i>4.5</i>	<i>12.1</i>	<i>4.5</i>	<i>45.5</i>	<i>35.7</i>	<i>21.2</i>	<i>5.4</i>	<i>56.8</i>	<i>67.0</i>
<i>ALL HABITAT CHARACTERISTICS</i>	<i>15.2</i>	<i>2.7</i>	<i>1.5</i>	<i>0</i>	<i>1.5</i>	<i>0</i>	<i>15.2</i>	<i>0.9</i>	<i>9.8</i>	<i>0.1</i>	<i>27.3</i>	<i>4.5</i>

Table 9. (cont'd)

Tree Characteristics	TRSW (31)		EUST (27)		HAWO (20)		HOWR (141)		MOBL (81)		NOFL (108)	
	UL	SL	UL	SL	UL	SL	UL	SL	UL	SL	UL	SL
DBH	96.2	86.6	64.9	35.1	98.5	86.6	99.2	97.2	98.5	94.5	90.2	61.1
Height	82.6	93.8	51.4	48.6	84.8	76.8	100	100	99.2	100	98.5	100
% Bark	97.7	99.1	54.0	46.0	97.7	95.5	100	100	100	100	78.6	92.9
Tree Status	99.2	99.1	49.8	50.2	78.0	92.9	100	99.1	78.6	92.9	98.5	99.1
Tree Species	98.5	100	53.7	46.3	100	100	100	100	100	100	100	100
<i>ALL TREE CHARACTERISTICS</i>	<i>77.3</i>	<i>80.4</i>	<i>56.8</i>	<i>43.8</i>	<i>64.4</i>	<i>62.5</i>	<i>97.0</i>	<i>92.9</i>	<i>68.2</i>	<i>84.8</i>	<i>62.1</i>	<i>52.7</i>
Microsite Characteristics												
Tree density (10-40 cm dbh)	96.2	83.9	91.7	96.4	77.3	67.9	100	100	100	100	99.2	96.3
Tree density (>40 cm dbh)	96.2	96.4	92.4	92.9	91.7	96.4	100	100	95.5	100	100	100
% Bare Ground	82.6	83.0	94.7	100	100	100	97.7	100	100	100	100	100
% Ground Cover	98.5	99.1	100	100	98.5	100	100	100	100	100	100	100
% Low Shrub	99.2	100	100	100	98.5	98.2	100	100	100	100	100	100
% Tall Shrub	100	100	100	100	99.2	99.1	100	100	100	99.1	100	100
Burn Severity	93.9	97.3	76.5	95.5	93.9	97.3	82.4	98.2	100	100	100	100
<i>ALL MICROSITE CHARACTERISTICS</i>	<i>68.9</i>	<i>58.9</i>	<i>61.4</i>	<i>89.3</i>	<i>62.1</i>	<i>65.2</i>	<i>81.1</i>	<i>98.2</i>	<i>81.8</i>	<i>88.4</i>	<i>99.5</i>	<i>96.4</i>
<i>ALL HABITAT CHARACTERISTICS</i>	<i>52.3</i>	<i>50.0</i>	<i>42.4</i>	<i>41.1</i>	<i>42.4</i>	<i>42.0</i>	<i>79.5</i>	<i>91.1</i>	<i>64.4</i>	<i>78.6</i>	<i>68.2</i>	<i>53.6</i>

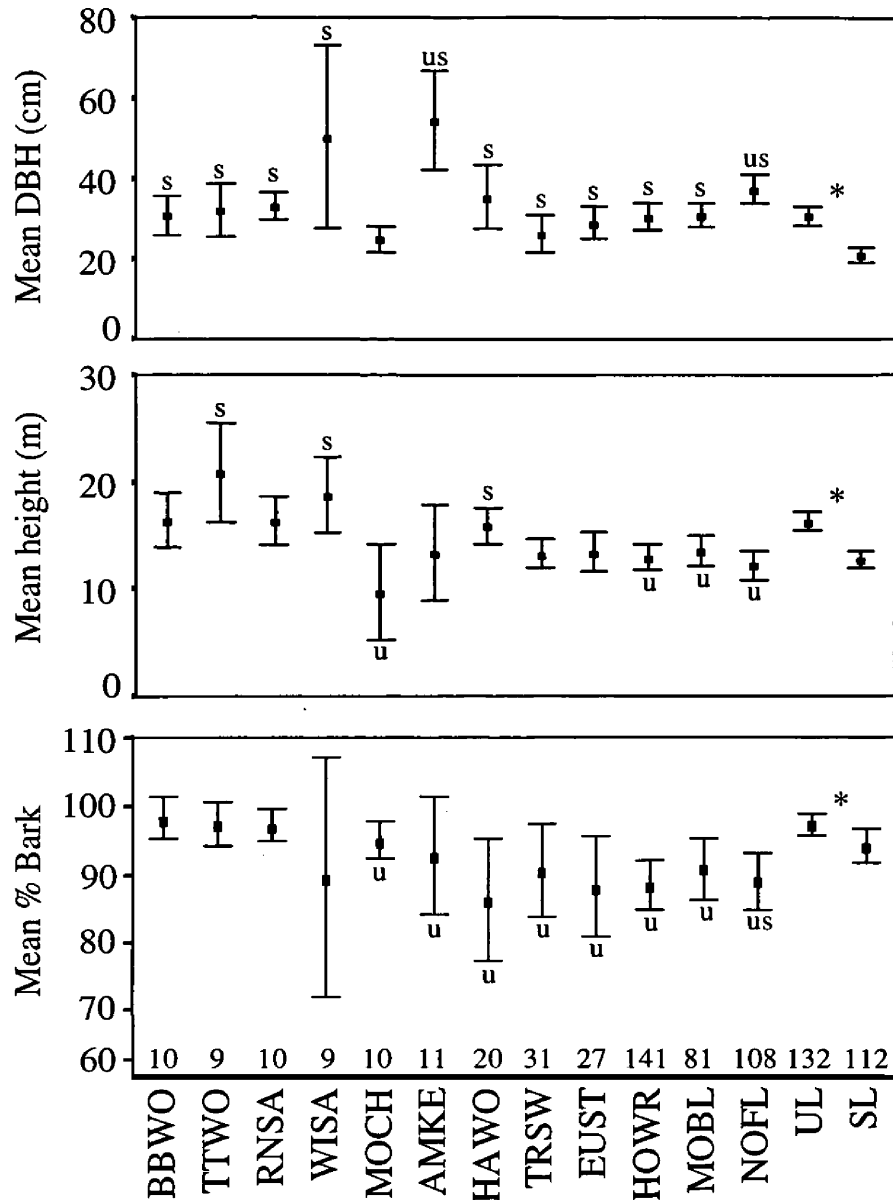


Figure 5. Mean nest tree characteristics (\pm 2SE) for cavity-nesting bird species plus random trees in unlogged (UL) and salvage-logged (SL) areas. Sample sizes listed above species abbreviation. Species abbreviations listed in Table 4. Small letters indicate significant differences in distributions from random trees in salvage-logged (s) or unlogged (u) areas. Letters above the bar indicate values higher than random, letters below the bar indicate values lower than random. Asterisks indicate significant differences between random trees in two treatments. ($p < 0.05$, Mann-Whitney U tests with Bonferonni adjustment for multiple comparisons).

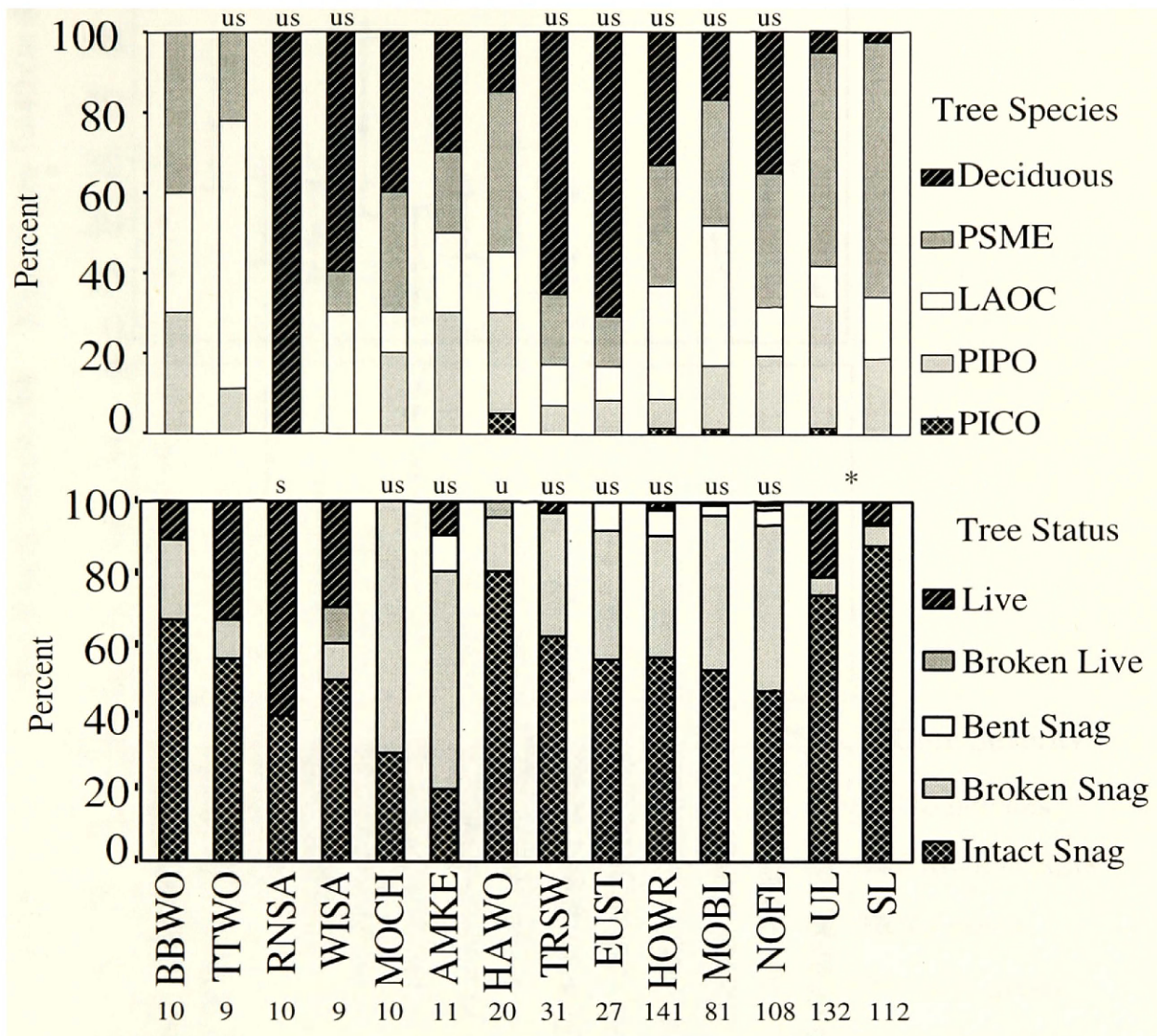


Figure 6. Frequency distributions of tree species and status of trees used by cavity-nesting birds, and of random trees in unlogged (UL) and salvage-logged (SL) areas. Sample sizes listed below bird species abbreviations. Bird species abbreviations given in Table 4. Tree species abbreviations: PSME=Douglas fir, LAOC=western larch, PIPO=ponderosa pine and PICO=lodgepole pine. Small letters indicate significant differences in distributions from random trees in salvage-logged (s) or unlogged (u) areas. Asterisks indicate significant differences between random trees in two treatments. ($p < 0.05$, X^2 Likelihood Ratio with Bonferonni correction for multiple comparisons).

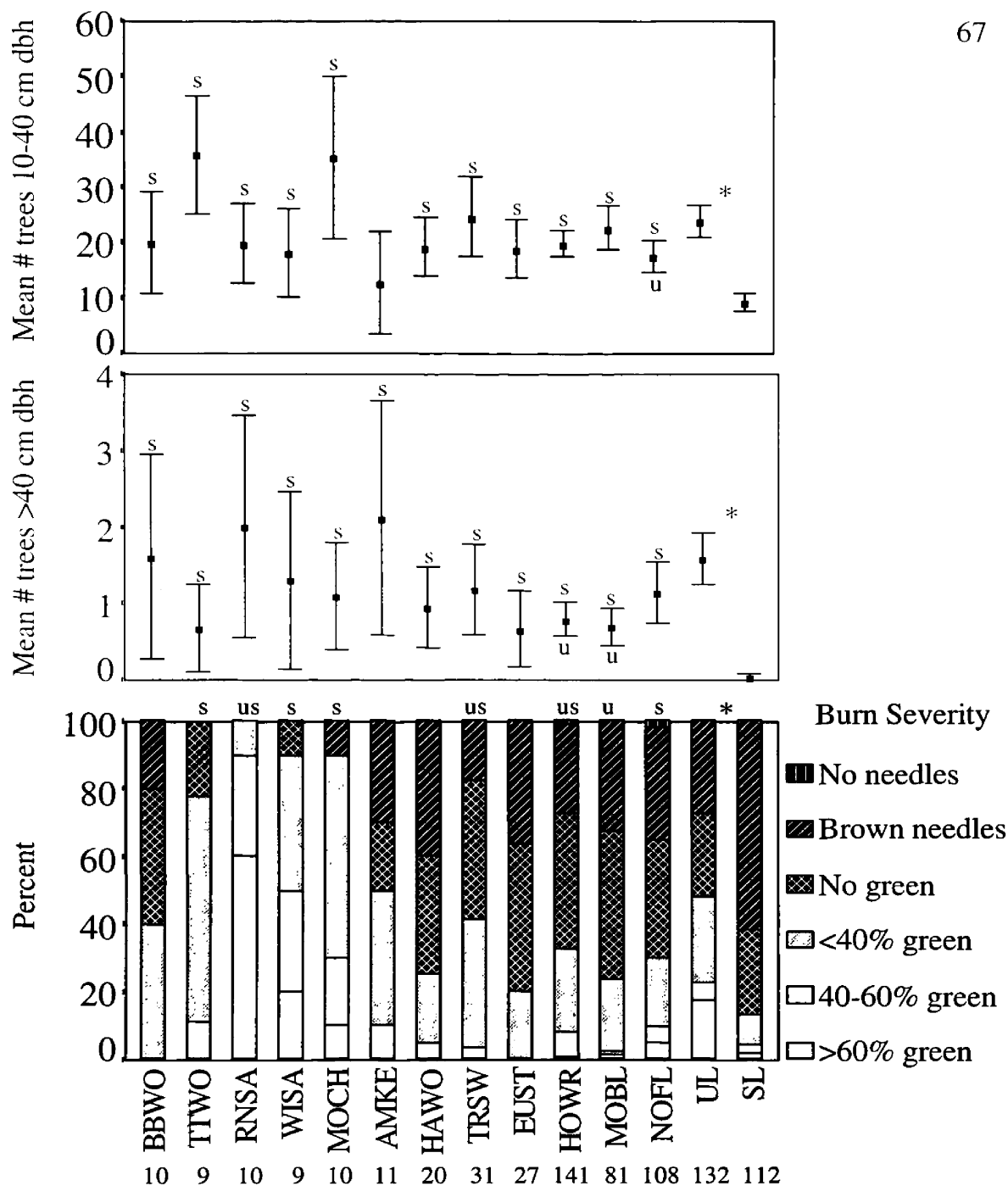


Figure 7. Nest microsite characteristics for cavity-nesting bird species plus random microsites in unlogged (UL) and salvage-logged (SL) areas. Mean ($\pm 2SE$) for tree density and frequency distribution for burn severity. Sample sizes below species abbreviations. Species abbreviations given in Table 4. Small letters indicate significant differences in distributions from random trees in salvage-logged (s) or unlogged (u) areas. For tree density, letters above the error bars indicate values higher than random, letters below the bars indicate values lower than random. Asterisks indicate significant differences between random trees in two treatments ($p < 0.05$, Mann-Whitney U tests for tree densities, X^2 for burn severity, with Bonferroni adjustment for multiple comparisons).

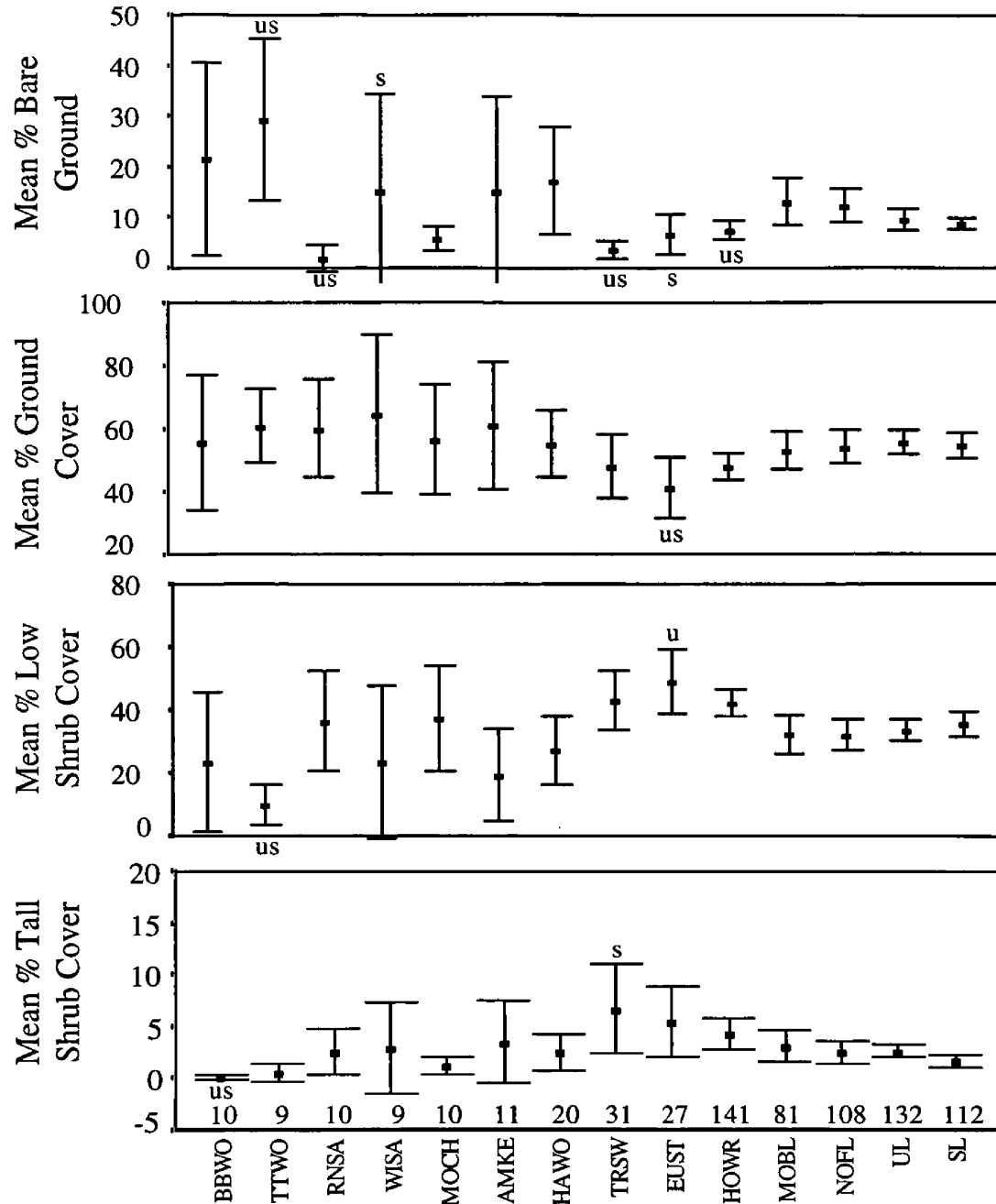


Figure 8. Mean nest microsite characteristics ($\pm 2SE$) for cavity-nesting bird species plus random trees in unlogged (UL) and salvage-logged (SL) areas. Sample sizes listed above species abbreviations. Species abbreviations given in Table 4. Small letters indicate significant differences in distributions from random trees in salvage-logged (s) or unlogged (u) areas. Letters above the bar indicate values higher than random, letters below the bar indicate values lower than random. ($p < 0.05$, Mann-Whitney U tests with Bonferonni adjustment for multiple comparisons).

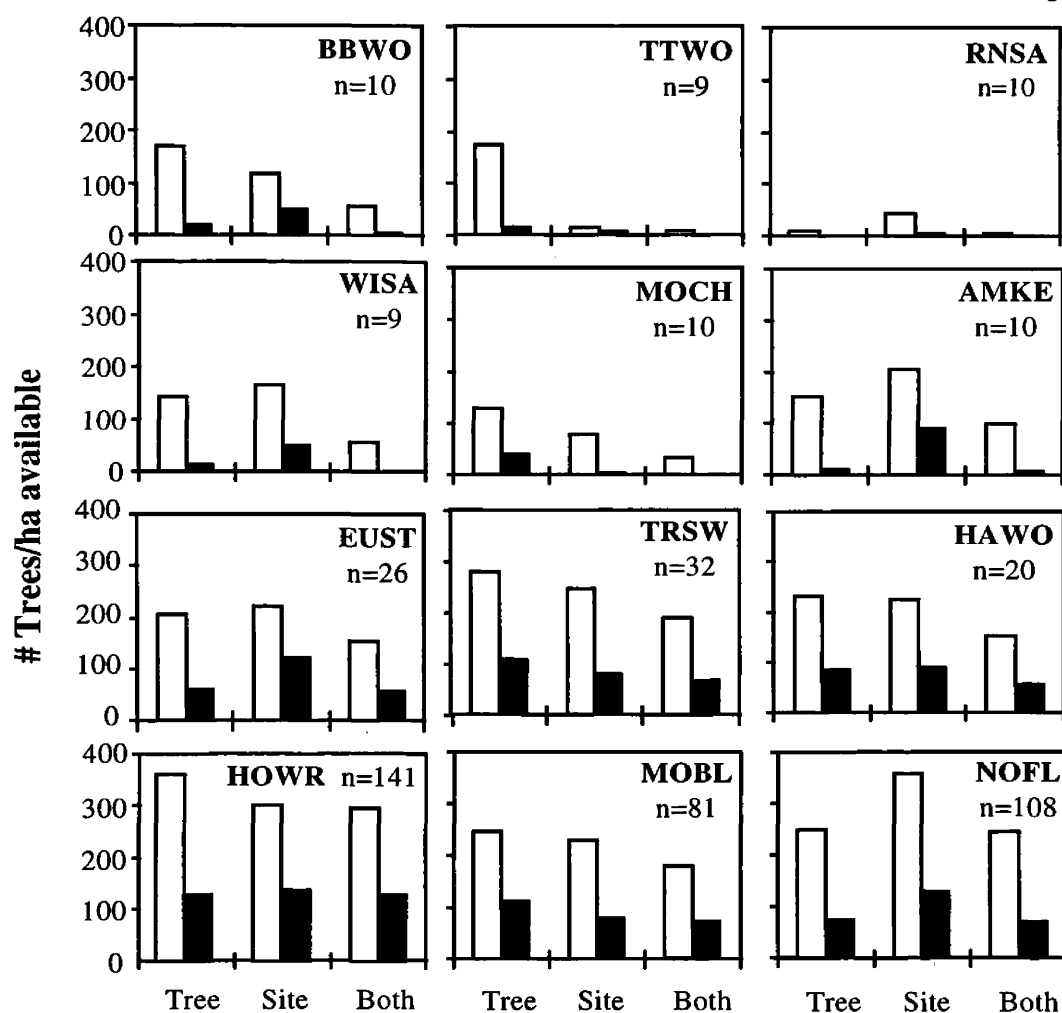


Figure 9. The number of suitable trees, associated microsites and both combined in unlogged (white) and unlogged (black) areas. Sample sizes for each species is the number of nest trees used to calculate suitability in random trees. Species abbreviations given in Table 4.

CHAPTER III

NESTING SUCCESS OF CAVITY-NESTING BIRDS IN SALVAGE-LOGGED VS. UNLOGGED BURNED FOREST

Introduction

Different habitat types may support different rates of predation, and thus different levels of nesting success for avian species (e.g., Picman 1988). For example, in the Midwest, birds in highly fragmented forests suffer from higher nest predation and nest parasitism, and so have lower reproductive success, compared to birds in less fragmented habitat (Robinson et al. 1995). In addition, the abundance of birds in a habitat type has often been assumed to be related to habitat suitability or high reproductive success rates, but this is not necessarily the case (Van Horne 1983, Brawn and Robinson 1996). The presence of birds in a given habitat type does not necessarily mean that habitat is suitable or that birds will experience high rates of nesting success.

Burned forest habitat usually supports high numbers of species (Caton 1996) and high densities of cavity-nesting birds (Harris 1982). Cavity-nesting birds appear to respond positively to the increased availability of food and to abundant potential nesting sites in post-fire habitat (Apfelbaum and Haney 1987, Raphael et al. 1987, Caton 1996).

Salvage-logging, or the removal of economically valuable dead and dying timber, is common after high-intensity, stand-replacement forest fires in the northwestern Rocky Mountains. Salvage-logging often changes forest structure due to the selective removal of large-diameter snags (standing dead trees) and snags of tree species thought to be most

valuable to wildlife (Thomas et al. 1979, Chapter II). Salvage-logged, burned forests generally have fewer species and lower densities of breeding cavity-nesting birds than unlogged, burned forest (Caton 1996), but some species persist in nesting in salvage-logged areas despite the major change in habitat features (Chapter I).

Data from a previous part of this study (Chapter II) showed that, when cavity-nesting birds nested in both unlogged and salvage-logged forest, characteristics of their nests, for some species, were different in the two treatments (Table 8, Chapter II). For example, Mountain Bluebird (*Sialia currucoides*) nests in unlogged areas were in taller trees with more bark cover compared to nests in salvage-logged areas (Table 8, Chapter II). Northern Flicker (*Colaptes auratus*) nested in different tree species in the two treatments, and nested in taller trees in unlogged areas (Table 8, Chapter II).

These differences in nest tree characteristics combined with differences in abundance between the two treatments, lead me to speculate that rates of nesting success may be different in the two habitat types. Birds may be able to nest in salvage-logged areas, but may suffer decreased reproductive success due to changes in habitat. These observations lead to the formulation of two questions in the current study: 1) Does cavity-nesting bird nesting success differ between salvage-logged and unlogged burned forest? 2) Which habitat variables are best associated with successful or failed nests?

Methods

Study Area

This study took place on the Blackfoot-Clearwater Wildlife Management Area, which is located about 80 km east of Missoula, MT. Elevation of the study area is between 1200 and 1500 m. A severe fire in October of 1991 burned approximately 1600 ha of grassland and mixed-conifer forest. Approximately 500 ha of timber was salvage-logged in the winter following the fire in a design that created an interspersed pattern of harvest treatments with unlogged control plots (Figure 1). Unlogged and salvage-logged forested areas were separated by grasslands. The burned forested areas consisted mainly of 50 to 150-year-old second-growth conifers [Douglas-fir (*Pseudotsuga menziesii*), western larch (*Larix occidentalis*), and ponderosa pine (*Pinus ponderosa*)] and occasional pockets of broad-leaved deciduous trees (*Populus* spp.).

Nests in five unlogged plots and five salvage-logged plots were selected for this study (Figure 1). The extent of salvage logging varied among plots, but in most cases all merchantable (>15 cm dbh, >4.5 m tall), fire-killed timber was removed. Plots for nest monitoring were selected based on accessibility and proximity to other plots.

Nest Monitoring

Three species of cavity-nesting birds [Northern Flicker, Mountain Bluebird and House Wren (*Troglodytes aedon*)] were selected for nest monitoring because they were known from earlier analysis (Chapter I) to be abundant in both treatment types. Nests were located as early in the breeding season as possible, and monitored every 3 to 5 days

to assess activity. Nests were watched from at least 20 m away for a maximum of 20 min. Each time a nest was monitored, an observer recorded any bird activity (e.g., building, incubating, feeding). If nests became inactive before their expected fledging date, observers recorded notes about the nest site and nest cavity in order to determine the cause of failure (e.g., predators, weather, physical damage). Nests were checked more frequently towards the end of the breeding season so fledging dates could be assessed as accurately as possible. Nesting chronologies were reconstructed after the breeding season was over, and daily survival rates for each species and each treatment were calculated using the Mayfield method (Mayfield 1961, Mayfield 1975, Hensler and Nichols 1981). Variances in daily survival rates were calculated to enable me to test for differences between treatments (Hensler and Nichols 1981).

Habitat Variables

Habitat characteristics of nests and nest microsites (the area within a 15-m-radius circle around the nest tree) were measured after the breeding season was finished. Tree size (diameter at breast height) was measured with a dbh tape. Cavity height and tree height were measured with a clinometer. Cavity type (excavated cavity, natural cavity, or natural crack) was recorded. Tree species and the status of the tree (live or dead; intact, bent, or with a broken or dead top) was recorded. The percent of bark remaining on the tree was visually estimated. To assess microsite characteristics, stakes were placed 15 m from the tree in the four cardinal directions. Ocular assessments of the percent of bare ground (bare soil), ground cover (herbaceous plants <25 cm tall), low shrub (herbaceous

plants > 25 cm tall and all woody plants <0.5 m), and tall shrub (woody plants > 0.5 m tall) were made in each quarter and then averaged for the nest microsite. These estimates for cover were made from a “birds-eye” perspective (i.e., only the top layer was estimated so the four estimates sum to 100%). Canopy cover was estimated at each stake and 1m from the tree, then was averaged for an estimate of microsite canopy cover. The number of trees in each quarter was counted in four size classes (<10 cm dbh, 10-20 cm dbh, 20-40 cm dbh, and > 40 cm dbh). Burn severity of the canopy in the microsite was rated on a subjective scale of one to six, 1) 100% green, 2) 40-60% green, 3) <40% green, 4) no green but brown needles, 5) no brown needles but some twigs, and 6) no twigs but some branches.

Habitat Analysis

Comparisons of habitat characteristics at successful versus failed nests were made for each species. Mann-Whitney U tests were used to compare numerical variables, and Chi-Square Likelihood Ratios were used to compare categorical variables. A Bonferonni correction for 17 simultaneous tests was used to assure appropriate p-values for significance (for $\alpha > 0.95$, $p < 0.0029$ and for $\alpha > 0.99$, $p < 0.0006$).

Results

A total of 172 nests were monitored for activity during the breeding season. Of these, 41 were dropped from the analysis because of incomplete nesting records. The remaining 131 nests were used in the current analysis (Table 10). Most causes of nest failure were unknown, but predation, physical damage (e.g., nest tree falling over or

snapping at cavity height), and apparent ousting by other species of cavity-nesting birds caused at least a quarter of nest failures (Table 11).

Daily Survival Rate

Mean daily survival rate was significantly higher for Northern Flickers in unlogged compared to salvage-logged areas (Figure 10). The trend was similar and more extreme for Mountain Bluebirds, but because of larger variances, the difference was not significant (Figure 10). House Wrens did equally well in salvage-logged and unlogged areas (Figure 10). Nesting success rates, calculated by raising the daily survival rate to the power of the average nesting period, ranged from 34.2% for Mountain Bluebirds in salvage-logged areas to 94.7% for Northern Flickers in unlogged areas (Table 11).

Habitat Characteristics

None of the 17 habitat variables measured at nest trees or their associated microsites were significantly different between successful and failed nests for either Northern Flickers or House Wrens (Table 13). For Mountain Bluebirds, the density of trees between 10 and 20 cm dbh was significantly higher at successful (mean=22.5 trees) than at failed (mean=9.7 trees) nests ($p < 0.05$) (Table 13). The only other variable that appeared to differ for Mountain Bluebirds was cavity type. All nests ($n=3$) in natural cavities failed, whereas only 11 (of 34) nests in excavated cavities failed. This difference was not significant.

Discussion

The physiognomy of the two treatments (salvage-logged vs. unlogged) was quite different. Unlogged plots had significantly larger and taller trees in higher densities compared to salvage-logged plots (Table 1, Chapter I). Trees in unlogged areas had more bark than trees in salvage-logged areas (Table 1, Chapter I). Unlogged plots had more live trees compared to salvage-logged plots, and correlating with this, unlogged plots were less severely burned compared to salvage-logged plots (Table 1, Chapter I). There was a higher proportion of intact snags in salvage-logged plots (Table 1, Chapter I). These physical differences in the type of habitat could relate to factors that affect nesting success.

The cause of failure for most nests in this study was unknown, but nest predation was a likely candidate, since it has been shown to be the major cause of nest failure for many other bird species (e.g., Martin and Roper 1988, Martin 1993, Morton et al. 1993, Filliater 1994). Possible nest predators present on the study area included black bear (*Ursus americanus*), striped skunk (*Mephitis mephitis*), chipmunk (*Eutamias* spp.), weasels (*Mustela* spp.), raccoon (*Procyon lotor*), red squirrel (*Tamiasciurus hudsonicus*), and American Kestrel (*Falco sparverius*). However, it was unknown whether the abundance or activity levels of predators was greater in salvage-logged compare to unlogged areas.

The only direct observation of nest predation during the time of this study was an American Kestrel depredating a Williamson's Sapsucker nest. American Kestrels are suspected to have caused several Mountain Bluebird nest failures in salvage-logged areas,

and may be an important predator influencing nest placement in some cavity-nesting bird species. American Kestrels nested in approximately equal densities in the two treatments (Table 5, Chapter I).

Fire-killed trees were susceptible to wind throw, and there were several cases of snapped or toppled nest trees throughout the breeding season. In fact, several nest trees snapped at the same height as nest cavities, indicating the cavities themselves actually weakened the tree and thereby indirectly caused nest failure.

There were four cases of nest failure due to “ousting” by other cavity-nesting bird species. All four of these cases were Mountain Bluebirds that lost their cavities to other species (two to House Wren and one each to Tree Swallow and Northern Flicker). Mountain Bluebirds appear to be less aggressive than other species of cavity-nesting bird, and proximity of their nests to other cavity-nesting bird species may influence nesting success in Mountain Bluebirds.

Data in the literature suggest that Northern Flickers have extremely high nesting success. Li and Martin (1991) had no Northern Flicker nest failures in three years of nest monitoring in unburned forest in Arizona ($n=34$). In the unlogged areas of the present study, only one Northern Flicker nest failed over the course of the breeding season. Johnson and Kermott (1994) reviewed several studies of cavity-nesting bird nesting success and reported that between 50 and 86% of Northern Flicker nests in four previous studies produced at least one young. By this measure of success, 95.8% of nests in unlogged areas were successful and only 70.8% of nests in salvage-logged areas were successful in this study.

Although the trend for success was similar in Mountain Bluebirds, the difference in daily survival rates in the two areas was not significant. Daily survival rates and nesting success in unlogged areas was similar to those reported by Li and Martin (1991) for Western Bluebirds in Arizona, but these measures were lower in salvage-logged areas. Erskine and McLaren (1976, reported in Johnson and Kermott 1994) found only 22% of Mountain Bluebird nests studied in British Columbia successfully produced at least one young. This is much lower than Mountain Bluebird nests in either forest type in the current study: seventy-two percent of nests in unlogged and 46.6% of nests in salvage-logged areas produced at least one young.

House Wrens appeared to do equally well in either unlogged or salvage-logged areas. Their daily survival rates and nesting success were similar to those reported by Li and Martin (1991). Johnson and Kermott (1994) reported 63% of House Wren nests in Wyoming successfully produced at least one young, which is slightly lower than in this study (approximately 77% in both unlogged and salvage-logged areas).

The three species monitored for nesting success in this study were fairly abundant in both unlogged and salvage-logged areas, though all three species nested in higher densities in unlogged areas. Since they do nest in both habitat types, their habitat requirements are obviously somewhat flexible (Chapter II). Birds that exhibit this flexibility in habitat requirements might be expected to do equally well in any habitat, and this does appear to be true for House Wrens. For the other two species, however, nesting success appears to be lower in salvage-logged areas. This suggests that the two forest habitats were not equally suitable, despite the relatively high nesting density in each.

It is surprising that only one of the habitat characteristics I measured was significantly related to nesting success for only one species. Factors that I suspected might be related to nest failure (e.g., height of nest trees and nest cavities) in fact appeared to be unrelated to reproductive success. Li and Martin (1991) found that both cavity height and nest concealment were related to nesting success for cavity-nesting birds in unburned forests in Arizona. Nest height was not related to nesting success in this study, and no measurements were made of nest concealment. However, since the study area consisted primarily of burned snags with little or no live vegetation, it is unlikely that the degree of concealment would be different between treatments or between successful and failed nests. Successful Mountain Bluebird nests had significantly higher densities of smaller-sized (10-20 cm dbh) trees in their microsites compared to failed nests. Nest trees surrounded by higher densities of similar trees may increase predator search time and subsequently decrease risk of predation (Martin and Roper 1988).

There were several nests monitored in this study that were clearly depredated as a result of their placement near the ground. For example, one Mountain Bluebird nest was located underground in an old root hole of a burned out tree. This nest was depredated almost immediately after it was found, and its demise was almost certainly related to its accessibility by predators. However, in a large sample of nests, habitat features like height of nest did not consistently relate to nesting success. It is possible that nest depredation could happen almost immediately after a nest is placed in an “inappropriate” location. If this were true, it would be difficult for observers to locate a sufficient sample of these nests.

The sample sizes in this study are close to the sample size of 20 recommended by Hensler and Nichols (1981). Limitations of time and personnel available for this study determined the sample size to some extent, but the lower abundance of nests in salvage-logged areas was also a limiting factor. Also, in forest types that have high nesting success rates, it is difficult to get a sufficient sample of nests in the “failed” category. For example, in this study, only one Northern Flicker nest failed in unlogged areas. This made it impossible to compare successful and failed nests within unlogged areas. With larger samples, one could assess differences between successful and failed nests within treatments.

Pulliam (1988) hypothesized that different habitat types may support different demographic rates. In “source” habitats, reproductive rates would exceed both juvenile and adult mortality, and would result in a surplus of individuals. In “sink” habitats, reproductive rates would fail to keep up with adult and juvenile mortality. Populations in “sink” habitats would require constant immigration from populations in “source” habitats in order to maintain stability. The alteration of habitat by salvage-logging could create “sink” habitats by decreasing both nest density and nesting success for some species. However, without estimates of juvenile and adult mortality and studies on larger spatial scales, this is only speculation. Conversely, higher cavity-nesting bird abundances in unlogged burned forest coupled with higher nesting success could also make unlogged burned forest a habitat “source” for some species. Again, the lack of mortality information and the small scale of the present study limit speculation about population dynamics in the two forest types. The present study does shed light on the potential

reduction in nesting success for some species of cavity-nesting birds in salvage-logged areas. Assessments of breeding density without estimates of nesting success may be misleading in terms of the potential of salvage-logged areas to support breeding cavity-nesting birds. Species that have apparently high populations but have low reproductive rates in managed areas could suffer population declines over time without immigration from more productive habitat types.

Despite flexibility in habitat requirements that allow some species to settle in both unlogged and salvage-logged areas, the difference in nesting success for Northern Flickers, and possibly for Mountain Bluebirds, suggests that the two forest habitats are not equally suitable for nesting. Although the habitat variables measured in the current study are not linked to success, it is possible that with larger sample sizes over larger areas, some measurable aspect of habitat could be quantified and linked with nesting success. Whether decreased nesting success is related to an increase in predators or some other aspect of physical habitat, remains to be seen. Identification of habitat features that correlate with high reproductive success could help to mitigate the effects of post-fire salvage-logging on cavity-nesting bird species.

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Table 10. Distribution of nests monitored for success among species and treatment types. Total nests monitored listed, number of failed nests listed in parenthesis. Species abbreviations in Table 4.

Treatment	Species			Total
	NOFL	MOBL	HOWR	
Unlogged	24 (1)	25 (7)	34 (8)	83 (16)
Salvage-logged	24 (7)	15 (8)	9 (2)	48 (17)
Total	48 (8)	40 (15)	43 (10)	131 (33)

Table 11. Nesting success for three species of cavity-nesting birds in salvage-logged and unlogged burned forest. Species abbreviations listed in Table 4.

Treatment	Species		
	NOFL	MOBL	HOWR
Unlogged	94.7%	66.9%	73.2%
Salvage-logged	66.6%	34.2%	79.3%

Table 12. Causes of nest failure for three species of cavity-nesting birds in salvage-logged and unlogged burned forest, including nests not monitored in this study.

Cause of Nest Failure	Number of nests (%)
Predation	4 (12.1%)
Physical Damage	3 (9.1%)
Ousted (by other species)	4 (12.1%)
Unknown	22 (66.7%)
Total	33

Table 13. Comparisons between successful vs. failed nests for all habitat characteristics measured. Means and standard errors listed for continuous variables. Frequency distributions listed for categorical variables. Asterisk indicates significant difference between successful and failed nests (Mann Whitney U tests with Bonferonni adjustment for multiple tests, $p < 0.05$).

Tree/Microsite Characteristics	House Wren		Mountain Bluebird		Northern Flicker		All Species Combined	
	Successful?		Successful?		Successful?		Successful?	
	Yes n=33	No n=10	Yes n=24	No n=13	Yes n=40	No n=8	Yes n=98	No n=33
DBH	25.9 1.75	22.6 1.55	30.4 2.61	31.4 3.39	35.5 2.49	35.4 2.79	31.0 1.40	29.9 1.93
Tree Height	12.3 1.15	11.1 1.84	13.0 1.17	13.5 2.02	12.3 1.11	9.8 2.70	12.5 0.67	11.8 1.24
Cavity Height	4.3 0.43	5.6 1.07	5.4 0.55	5.5 1.08	5.3 0.56	5.4 1.78	5.0 0.31	5.5 0.71
Cavity Type								
Natural Cavity	27.3	30.0	0	21.4	12.5	87.5	14.6	21.9
Natural Crevice	18.2	10.0					6.3	3.1
Excavated	54.5	60.0	100.0	78.6	87.5	87.8	79.2	75.0
Percent Bark	87.9 3.51	81.8 8.88	87.7 4.92	84.9 7.81	85.2 4.09	85.8 10.84	86.8 2.38	84.2 5.01
Tree species								
<i>lodgepole pine</i>	6.3	0	4.2	0			3.1	
<i>ponderosa pine</i>	6.3	10.0	25.0	7.7	12.5	25.0	13.5	12.9
<i>western larch</i>	21.9	20.0	33.3	38.5	17.5	12.5	22.9	25.8
<i>Douglas fir</i>	25.	40.0	29.2	38.5	37.5	50.0	31.3	41.9
<i>deciduous spp.</i>	40.6	30.0	8.3	15.4	32.5	12.5	29.2	19.4
Tree status								
Intact snag	71.9	40.0	60.0	64.3	52.5	37.5	60.8	50.0
Broken snag	21.9	60.0	40.0	28.6	40.0	50.0	34.0	43.8
Bent snag	6.3				5.0	12.5	4.1	
Broken-topped live				7.1	2.5		1.0	6.3
Tree density								
<10 cm dbh	9.5 1.87	6.5 3.60	16.6 4.90	4.9 1.74	11.2 1.92	6.8 2.82	12.0 1.63	5.8 1.51
10-20 cm dbh	13.6 1.80	14.1 4.23	22.5* 3.36	9.7 1.88	14.6 2.27	4.3 0.84	16.3 1.44	10.1 1.74
20-40 cm dbh	8.1 1.38	11.6 3.80	9.2 1.86	8.8 2.57	6.2 0.90	3.3 1.82	7.6 0.76	8.6 1.81
>40 cm dbh	1.2 0.31	0.9 0.46	0.5 0.21	1.1 0.40	0.8 0.26	0.8 0.83	0.8 0.16	1.0 0.28
% bare ground	4.0 0.84	6.3 1.48	8.2 1.11	5.3 1.02	6.3 0.91	8.8 2.90	6.0 0.56	6.4 0.95

Table 13 (cont'd)

Tree/microsite Characteristics	House Wren		Mountain Bluebird		Northern Flicker		Combined	
	Successful?		Successful?		Successful?		Successful?	
	Yes n=33	No n=10	Yes n=24	No n=13	Yes n=40	No n=8	Yes n=98	No n=33
% ground cover	55.1 3.73	62.4 7.99	61.3 3.76	59.8 6.89	57.8 3.19	53.3 10.45	57.8 2.04	59.0 4.58
% low shrub	35.9 3.30	30.0 7.88	27.4 3.25	33.5 6.63	32.4 3.02	36.6 8.78	32.3 1.86	33.2 4.28
% tall shrub	5.2 1.59	1.4 1.03	3.2 1.42	1.6 0.60	3.5 0.94	1.4 0.50	4.0 0.75	1.5 0.42
Canopy Cover	5.7 0.64	9.3 1.88	7.4 1.04	5.3 1.57	4.8 0.61	3.6 0.89	5.77 0.43	6.09 1.00
Burn severity								
>60% green					2.5		1.0	
40-60% green	3.0				2.5		2.0	
<40% green	24.2	30.0	16.0	13.3	22.5	25.0	21.4	21.2
No green, brown needles	42.4	40.0	48.0	33.3	32.5	25.0	39.8	33.3
No needles, some twigs	27.3	30.0	36.0	53.3	40.0	50.0	34.7	45.5
No twigs, some branches	3.0						1.0	

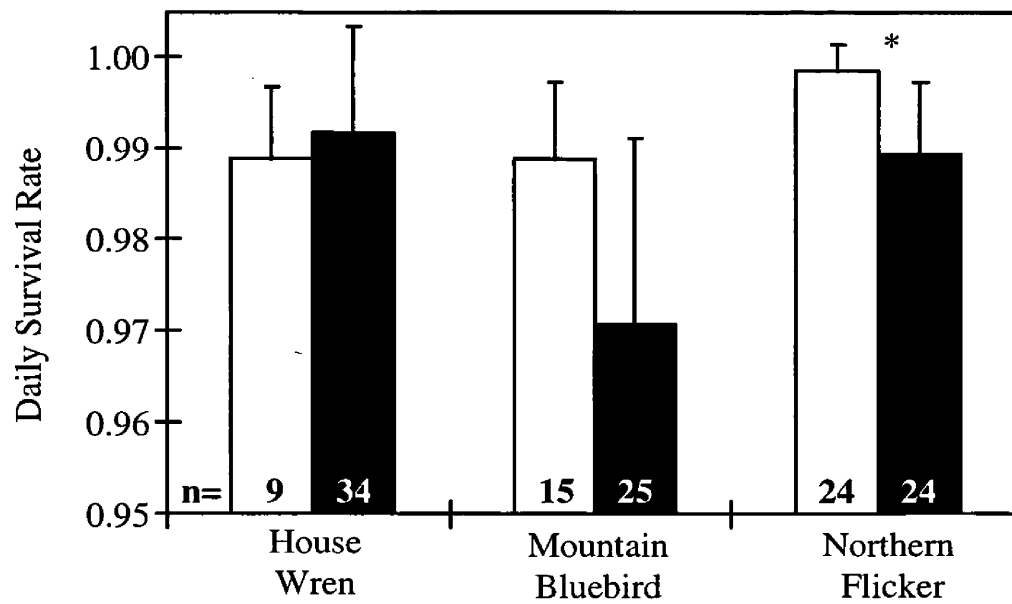


Figure 10. Mean daily survival rates (± 2 SE) of three species of cavity nesting birds in unlogged (white bars) compared to salvage-logged (black bars) burned forest. Asterisk indicates a significant difference between treatments.

Appendix. Summary of habitat characteristics for cavity-nesting species. Mean (SD) with range in italics listed for numerical variables. Frequency distributions listed for categorical values.

Species	N	DBH (cm)	Tree Height (m)	% Bark	Tree Species ^a	Tree Status ^b
BBWO	10	30.7 (7.71) <i>22.6 - 44.6</i>	16.4 (4.02) <i>9.5 - 23.8</i>	98.0 (1.89) <i>85 - 100</i>	30% PIPO 30% LAOC 40% PSME	67% IS 22% BS 11% IL
TTWO	9	31.9 (9.73) <i>20.7 - 51.9</i>	20.8 (6.88) <i>13.5 - 35.3</i>	97.2 (5.07) <i>85 - 100</i>	11% PIPO 67% LAOC 22% PSME	56% IS 11% BS 33% IL
RNSA	10	q	15.7 (3.72) <i>10.1 - 20.3</i>	97.0 (3.50) <i>90 - 100</i>	100% DECID	40% IS 60% IL
WISA	9	47.6 (37.0) <i>23.2 - 140.0</i>	18.4 (5.78) <i>8.0 - 27.7</i>	98.1 (3.48) <i>90 - 100</i>	22% LAOC 11% PSME 67% DECID	44% IS 11% BS 11% BL 33% IL
MOCH	10	24.7 (5.29) <i>18.5 - 32.5</i>	9.7 (7.13) <i>1.3 - 20.7</i>	94.8 (4.09) <i>90 - 100</i>	20% PIPO 10% LAOC 30% PSME 40% DECID	30% IS 70% BS
AMKE	10	54.3 (19.7) <i>28.6 - 79.3</i>	13.2 (4.6) <i>4.7 - 25.5</i>	87.9 (18.0) <i>55 - 100</i>	40% PIPO 20% LAOC 20% PSME 30% DECID	30% IS 60% BS 10% BS
HAWO	20	35.3 (17.55) <i>17.5 - 83.0</i>	15.8 (3.82) <i>9.6 - 24.2</i>	86.0 (19.92) <i>50 - 100</i>	5% PICO 25% PIPO 15% LAOC 40% PSME 66% DECID	84% IS 11% BS 5% BL
TRSW	32	26.1 (12.38) <i>14.6 - 66.2</i>	13.2 (3.72) <i>4.9 - 21.4</i>	88.7 (20.26) <i>15 - 100</i>	6% PIPO 9% LAOC 19% PSME 66% DECID	62% IS 34% BS 3% IL
EUST	26	28.7 (9.34) <i>17.8 - 61.1</i>	13.2 (4.60) <i>5.5 - 22.4</i>	87.9 (18.0) <i>30 - 100</i>	8% PIPO 12% LAOC 12% PSME 69% DECID	54% IS 42% BS 8% BNS
HOWR	112	30.4 (20.0) <i>12.7 - 140.0</i>	12.9 (7.09) <i>0.6 - 37.3</i>	88.1 (21.40) <i>5 - 100</i>	2% PICO 7% PIPO 30% LAOC 30% PSME 31% DECID	59% IS 34% BS 1% BL 7% BNS 1% IL
NOFL	108	37.4 (18.57) <i>17.2 - 119.4</i>	12.2 (7.17) <i>0.9 - 30.0</i>	88.1 (21.5) <i>10 - 100</i>	16% PIPO 12% LAOC 40% PSME 32% DECID	44% IS 49% BS 2% BL 5% BS
MOBL	79	130.8 (12.9) <i>14.6 - 66.2</i>	12.2 (7.17) <i>4.9 - 21.4</i>	88.1 (21.5) <i>15 - 100</i>	1% PICO 15% PIPO 34% LAOC 35% PSME 15% DECID	52% IS 44% BS 2% BL 2% BNS

Appendix A. (cont'd)

Species	# Trees >10cm dbh	# Trees 10-40 cm dbh	# Trees >40 cm dbh	% Bare Ground	% Ground Cover	% Low Shrub	% Tall Shrub	Burn Severity ^c
BBWO	21.6 (14.21) 6 - 56	20.0 (14.79) 2 - 56	1.6 (2.12) 0 - 6	21.3 (30.0) 0 - 90	55.4 (34.0) 5 - 87.5	23.2 (35.0) 0 - 95	0.1 (0.4) 0 - 1.2	40% 3 40% 4 20% 5
TTWO	36.6 (16.60) 11 - 58	35.9 (16.06) 11 - 56	0.67 (0.87) 0 - 2	29.1 (24.1) 8 - 80	60.8 (17.6) 20 - 77.5	9.6 (9.8) 0 - 29	0.4 (1.3) 0 - 3.8	11% 2 67% 3 22% 4
RNSA	21.7 (12.0) 7 - 37	19.7 (11.34) 6 - 35	2.0 (2.31) 0 - 7	1.4 (3.2) 0 - 10	60.0 (24.4) 30 - 90	36.1 (25.2) 8.8 - 70	2.5 (3.4) 0 - 20	64% 1 27% 2 9% 3
WISA	18.6 (13.6) 0 - 47	35.3 (23.1) 0 - 46	0.8 (0.8) 0 - 2	10.0 (20.0) 0 - 50	64.3 (37.6) 0 - 100	23.1 (36.4) 0 - 100	2.8 (6.7) 0 - 20	11% 1 33% 2 44% 3 11% 4
MOCH	36.4 (22.7) 18 - 79	35.3 (23.1) 16 - 79	1.1 (1.1) 0 - 3	5.7 (3.8) 0 - 11	56.4 (27.5) 5-80	37.1 (26.5) 12.5 - 90	1.1 (1.3) 0 3.8	10% 1 20% 2 60% 3 10% 5
AMKE	13.8 (12.4) 2 - 40	12.6 (13.3) 1 - 39	12.1 (2.2) 0 - 7	15.2 (29.4) 0 - 95	61.0 (31.8) 5 - 100	19.1 (23.4) 0 - 54	3.4 (6.3) 0 - 20	10% 1 40% 3 20% 4 30% 5
HAWO	20.0 (11.7) 5 - 47	19.1 (11.6) 5 - 47	0.9 (1.2) 0 - 4	15.6 (22.0) 0 - 90	55.0 (23.6) 10 - 94	27.0 (24.3) 0 - 75	2.5 (4.1) 0 - 16	5% 1 20% 3 35% 4 40% 5
TRSW	26.0 (18.4) 4 - 102	24.8 (19.4) 2 - 102	1.3 (1.6) 0 - 6	2.5 (3.8) 0 - 13	48.5 (26.4) 15 - 100	43.3 (24.8) 0 - 80	2.5 (3.4) 0 - 31	3% 1 56% 3 41% 4 19% 5
EUST	19.5 (12.5) 1 - 50	18.9 (12.2) 1 - 50	0.6 (1.2) 0 - 4	4.8 (8.0) 0 - 30	40.0 (23.8) 0 - 100	49.0 (25.0) 0 - 100	5.9 (8.7) 0 - 33	19% 3 44% 4 37% 5
HOWR	22.0 (14.7) 0 - 87	20.5 (14.4) 0 - 84	0.9 (1.4) 0 - 8	5.7 (7.8) 0 - 50	50.6 (24.0) 0 - 100	49.0 (25.0) 0 - 100	4.1 (8.2) 0 - 53	1% 1 6% 2 25% 3 39% 4 28% 5 1% 6
NOFL	19.4 (15.6) 1 - 86	17.4 (14.1) 1 - 85	1.2 (2.1) 0 - 12	8.7 (10.3) 0 - 81.3	54.6 (22.8) 0 - 100	34.4 (21.7) 0 - 100	2.3 (3.9) 0 - 30.0	5% 1 6% 2 22% 3 34% 4 33% 5 1% 6
MOBL	24.4 (18.5) 1 - 102	23.8 (19.1) 0 - 102	0.7 (1.1) 0 - 5	6.4 (5.1) 0 - 21.3	60.5 (21.7) 1.3 - 92.5	30.7 (20.4) 2.5 - 73.8	2.4 (5.3) 0 - 28.8	1% 1 1% 2 20% 3 42% 4 36% 5

^a PICO=*Pinus contorta*, PIPO=*Pinus ponderosa*, LAOC=*Larix occidentalis*, PSME=*Pseudotsuga menziesii*, DECID=*Populus* spp., ^b IS=intact snag, BS=broken snag, BNS=bent snag, IL=intact live

^c 1=>60% green, 2=40-60% green, 3=<40% green, 4=no green, brown needles, 5=no needles, some twigs, 6=no twigs, some branches.